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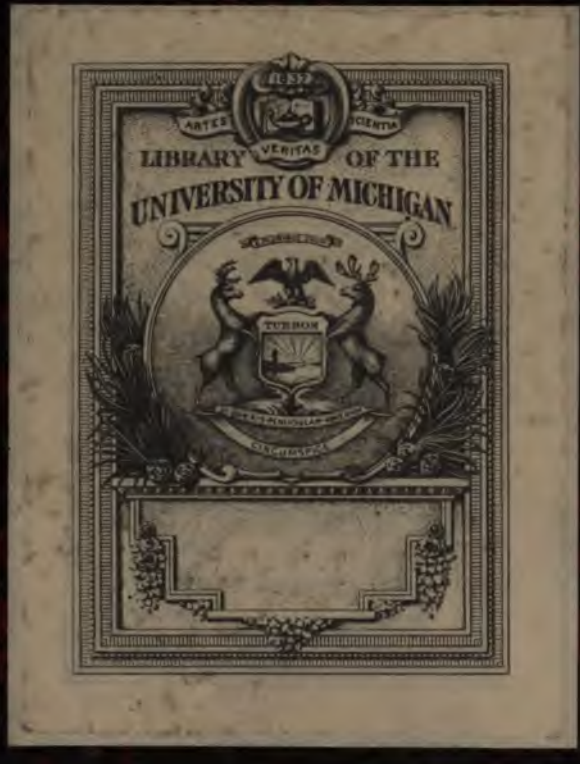
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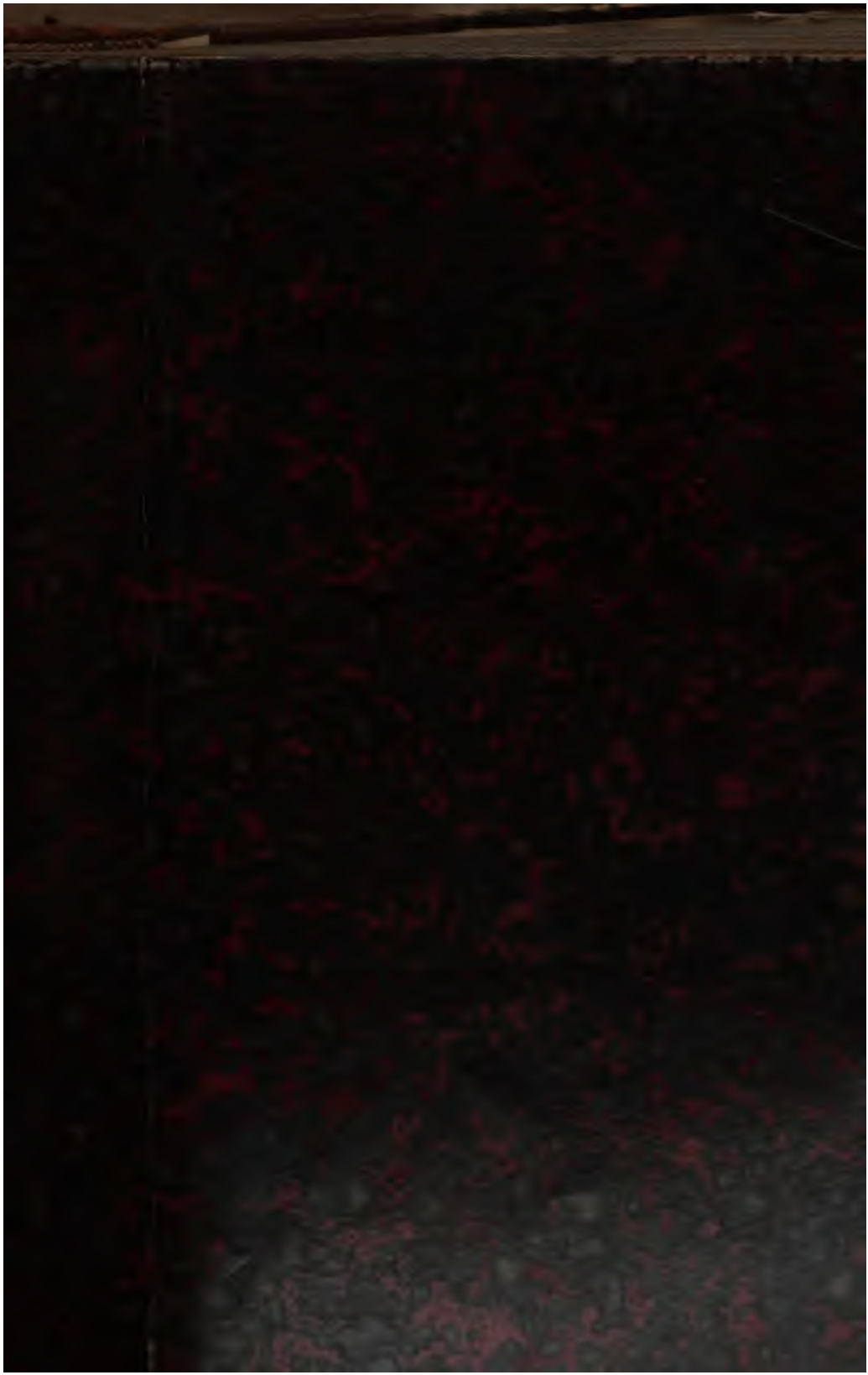

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TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

MECHANICAL ENGINEERS.

VOL. XXII.

XLIIND MEETING, NEW YORK CITY, 1900.
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OFFICERS

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS,

1900–1901,

FORMING THE STATUTORY COUNCIL.

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SECRETARY.

PROF. F. R. HUTTON.....No. 12 West 31st St., New York, N. Y.

164431

HONORARY COUNCILLORS.

Past Presidents of the Society.

R. H. THURSTON	1880—1882	Ithaca, N. Y.
E. D. LEAVITT	1882—1883	Cambridgeport, Mass.
JOHN E. SWEET	1883—1884	Syracuse, N. Y.
COLEMAN SELLERS	1885—1886	Philadelphia, Pa
HORACE SEE	1887—1888	New York City.
HENRY R. TOWNE	1888—1889	Stamford, Conn.
OBERLIN SMITH	1889—1890	Bridgeton, N. J.
ROBERT W. HUNT	1890—1891	Chicago, Ill.
CHARLES H. LORING	1891—1892	Brooklyn, N. Y.
CHARLES E. BILLINGS*	1895	Hartford, Conn.
JOHN FRITZ	1895—1896	Bethlehem, Pa.
WORCESTER R. WARNER	1896—1897	Cleveland, Ohio.
CHARLES WALLACE HUNT	1897—1898	New York City.
GEORGE W. MELVILLE	1898—1899	Washington, D. C.
CHARLES H. MORGAN	1899—1900	Worcester, Mass.

[NOTE.—The former Presidents of the Society are members of the Council for life or during their retention of active membership in the Society.]

*Unexpired term of E. F. C. Davis.

NOTE.

The considerable bulk of the annual volume of Transactions has induced the Publication Committee to direct the insertion of a summary of the Society membership in place of the complete list of members which was published in earlier volumes. The summary attaching to this issue is that which appears in the catalogue of the Society issued with corrections to July, 1901. Reference for the complete list should be made to the twenty-third catalogue issued on that date. The summary is as follows :

FOREIGN COUNTRIES.

	Membership.		Membership.
Africa (East)	1	Great Britain (England)	40
" (South)	7	" " (Scotland)	4
Australia	3	Holland	2
" (South)	1	India	1
" (West)	1	Italy	1
Belgium	3	Japan	6
Canada	16	Mexico	3
Central America	1	Norway	2
China	3	Russia	6
Cuba	4	South America	6
France	11	Sweden	5
Germany	10	Switzerland	1

Total foreign membership.....138

UNITED STATES.

	Membership.		Membership.
Alabama	4	Missouri	31
Arkansas	3	Montana	10
California	26	Nebraska	2
Colorado	24	New Hampshire	14
Connecticut	104	New Jersey	120
Delaware	10	New York	607
District of Columbia	26	North Carolina	2
Florida	1	Ohio	160
Georgia	6	Oregon	2
Illinois	136	Pennsylvania	325
Indiana	31	Porto Rico	2
Iowa	5	Rhode Island	42
Kansas	4	South Carolina	4
Kentucky	4	Tennessee	2
Louisiana	8	Texas	3
Maine	11	Utah	2
Maryland	32	Vermont	7
Massachusetts	202	Virginia	25
Michigan	53	Washington	4
Minnesota	9	West Virginia	5
Mississippi	2	Wisconsin	43

Total membership in the United States.....2,113

GEOGRAPHICAL SUMMARY.

Total foreign membership	138
Total membership in United States	2,113
Present address unknown *	3
Total membership	2,254

SUMMARY OF MEMBERSHIP BY GRADES.

Honorary members	19
Members	1,578
Associates	151
Junior members	506
Total membership	2,254

* These are John Breckenridge Fleming, Arthur Gibson, and J. H. Pendleton, and if any member knows their present addresses, he will confer a favor by advising the Secretary of them.

RULES OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

ART. 1. The objects of the AMERICAN SOCIETY OF MECHANICAL ENGINEERS are to promote the Arts and Sciences connected with Engineering and Mechanical Construction, by means of meetings for social intercourse and the reading and discussion of professional papers, and to circulate, by means of publication among its members, the information thus obtained.

ART. 2. All persons connected with engineering may be eligible for admission into the Society.

ART. 3. The Society shall consist of Honorary Members, Members, Associates, and Juniors.

ART. 4. Honorary Members, not exceeding twenty-five in number, may be elected. They must be persons of acknowledged professional eminence.

ART. 5. To be eligible as a Member, the candidate must be not less than thirty years of age, and must have been so connected with engineering as to be competent as a designer or as a constructor, or to take responsible charge of work in his department, or he must have served as a teacher of engineering for more than five years.

NOTE.—The Rules of the Society, adopted in 1880, were in force until 1884, when they received general revision by a careful committee, whose report, distributed by letter ballot, was adopted November 5, 1884. In December, 1894, a similar extensive revision was made under direction of the Council, and the present rules are those of 1894. They include the amendments made in 1889, 1891, 1893, and 1898, which were the only changes since the revision of 1884.

ART. 6. To be eligible as an Associate the candidate must be not less than twenty-six years of age, and must have the other qualifications of a member; or he shall have been so connected with engineering as to be competent to take charge of work, and to coöperate with engineers.

ART. 7. To be eligible as a Junior, the candidate must have had such engineering experience as will enable him to fill a responsible position, or he must be a graduate of an engineering school.

ART. 8. All Honorary Members, Members, and Associates shall be equally entitled to the privileges of membership. Juniors shall not be entitled to vote, nor to be officers of the Society.

ART. 9. Nominees for Honorary Membership must be proposed by at least five Members who are not officers of the Society. References shall not be required of a nominee for Honorary Membership, but the grounds upon which the application is made must be fully set forth in writing and signed by the proposers.

ART. 10. A candidate for admission to the Society, as a Member or as an Associate, must make an application on a form to be prepared by the Council, which shall contain a written statement giving a complete account of his engineering experience and an agreement that he will, if elected, conform to the laws, rules, and requirements of the Society. He must refer to at least five Members or Associates to whom he is personally known. A candidate for admission to the Society as a Junior must make an application on the same form, and refer to not less than three Members or Associates to whom he is personally known.

Applications for membership from engineers who are not resident in the United States and Canada, and who may be so situated as not to be personally known to five Members of the Society, as required in the foregoing paragraph, may be recommended for ballot by five Members of the Council, after sufficient evidence has been secured which shall show that in their opinion the applicant is worthy of admission to the grade which he seeks.

ART. 11. The referees for each candidate for admission to the Society shall be requested to make a confidential communication on a form to be prepared by the Council, setting forth in detail

such information, personally known by the referee, as shall enable the Council to arrive at a proper estimate of the eligibility of the candidate for admission to the Society. Such confidential communications shall be destroyed by the Secretary as soon as the vote has been officially declared.

ART. 12. All applications for membership must be presented to the Council, and this body shall consider each application, assigning to each, with the applicant's consent, the grade in the Society to which, in its opinion, his qualifications entitle him. The names of those candidates recommended for election by the Society shall be immediately printed on a ballot, and the ballot mailed at once by the Secretary to each voting member of the Society. Persons desiring to change their grade of membership from junior to associate or from associate to member shall make an application in the same manner and on the same form as that required for a new applicant.

ART. 13. A member entitled to vote may leave the name of any candidate on the ballot untouched to vote in favor of the admission of the candidate to the Society, or he may erase the name to vote against it. He shall enclose the ballot so approved by him in a sealed blank envelope, and enclose this envelope in a second envelope, on which he shall write his name, and mail the same to the Secretary of the Society. A ballot without such endorsement shall be rejected as defective. The rejection of a candidate by seven voters shall defeat his election.

ART. 14. The aforesaid envelopes containing the ballots shall be opened by the Council, at any meeting thereof, and the names of those elected shall be announced in the next meeting of the Society. The names of applicants not elected shall not be announced, nor recorded in the proceedings.

ART. 15. Endorsers of any applicant not elected may, within three months after such failure to be elected, lay before the Council written evidence that an error was then made. The Council may then, by a three-fourths vote, order another similar ballot by the Society, in which case thirteen negative votes shall be required to defeat the candidate.

ART. 16. Honorary members shall be elected by the unanimous vote of the Council, through a letter ballot, not less than sixty days subsequent to the proposal, a notice of which proposed election shall have been mailed at once by the Secretary to each member of the Council.

ART. 17. Each person elected, excepting honorary members, must subscribe to the Rules of the Society, and pay the initiation fee before he can receive a certificate entitling him to the rights and privileges of the Society, and to wear the emblem appropriate to his grade. If this payment is not made within six months of the election, the same shall be void, unless the time is extended by the Council. The emblems of each grade of membership shall be worn by those only who belong to that grade.

ART. 18. The initiation fee of a member or an associate shall be twenty-five dollars, and the annual dues shall be fifteen dollars, payable in advance. The initiation fee of a junior shall be fifteen dollars, and his annual dues ten dollars, payable in advance. A junior being promoted to any other grade of membership shall pay an additional initiation fee of ten dollars. Any member or associate may become a Life Member in the same grade, by the payment of two hundred dollars at one time, and shall not be liable thereafter to annual dues.

The Council shall have the power, for special reasons, by unanimous vote, through a letter ballot, to admit to life membership, without the payment of the sum above named, such person as for a long term of years has been a member or an associate, when such a procedure would in its judgment be for the best interests of the Society; *provided*, that notice of such action shall have been given at a previous meeting of the Council.

ART. 19. Any member of the Society in arrears may, at the discretion of the Council, be deprived of the publications of the Society, or, when in arrears for one year, he may be stricken from the list of members. Such person may be restored to the privileges of membership by the Council on payment of all arrears.

ART. 20. The affairs of the Society shall be managed by a Council, consisting of a President, six Vice-Presidents, nine Managers, and a Treasurer, who shall also be the Trustees of the Society.

All past (ex) Presidents of the Society, while they retain their membership therein, shall be known as Honorary Councillors, and shall be entitled to receive notices of all meetings of the Council and may take part in any of its deliberations; they shall be entitled to vote upon all questions except such as affect the legal rights or obligations of the Society or its members.

ART. 21. The members of the Council shall be elected from among the members and associates of the Society at the annual meetings, and shall hold office as follows:

The President and the Treasurer for one year; and no person shall be eligible for immediate re-election as President who shall have held that office for two consecutive years; the Vice-Presidents for two years, and the Managers for three years; and no Vice-President or Manager shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected.

ART. 22. A Secretary, who shall be a member of the Society, shall be appointed for one year by a majority of the members of the Council at its first meeting after the annual election, or as soon thereafter as the votes of a majority of the members of the Council can be secured for a candidate. The Secretary may be removed by a vote of twelve members of the Council, at any time after one month's notice has been given him by a majority of its members to show cause why he should not be removed, and he has been heard to that effect. The Secretary may take part in any of the deliberations of the Council, but shall not have a vote therein. His salary shall be fixed for the time he is appointed by a majority vote of the Council.

ART. 23. At each annual meeting, a President, three Vice-Presidents, three Managers, and a Treasurer shall be elected, and the term of office of each shall continue until the end of the meeting at which their successors are elected.

ART. 24. The duties of all officers shall be such as usually pertain to their offices or may be delegated to them by the Council or by the Society. The Council may, in its discretion, require bonds to be given by the Treasurer.

ART. 25. The Council may, by vote of a majority of all its members, declare the place of any officer vacant, on his failure for one year, from inability or otherwise, to attend the Council meetings, or to perform the duties of his office. All such vacancies and those occurring by death or resignation shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor was elected or appointed; *provided*, that the said appointment shall not render him ineligible at the next annual meeting.

ART. 26. Five members of the Council shall constitute a quorum. Members of the Council absent from a meeting may vote by letter upon subjects stated in the call for the meeting, said vote to be deposited with the Secretary.

ART. 27. The President on assuming office shall appoint a Finance Committee and a Publication Committee and a Library Committee of five members each. The appointment of two members of each Committee shall expire at the end of each year. The Secretary shall, *ex officio*, be a member of all three committees.

ART. 28. The Finance Committee shall have power to order all ordinary or current expenditures, and shall audit all bills therefor. No bill shall be paid except upon their audit. When special appropriations are ordered by the Society, they shall not take effect until they have been referred to the Council and Finance Committee in conference.

ART. 29. It shall be the duty of the Publication Committee to receive all papers contributed, and to decide upon which papers or parts of the same shall be presented at the professional meetings of the Society. They shall see that all editorial revisions of the proceedings, papers, discussions, and reports are made; and to decide what parts of the same shall be published in the proceedings of the Society. The Council may, at its discretion, revise any action of the Publication Committee.

ART. 30. It shall be the duty of the Library Committee to take charge of the collection of all material for the Library of the Society, and to supervise all regulations for its use.

ART. 31. At the regular meeting preceding the annual meeting a Nominating Committee of five members, not officers of the Society, shall be appointed, and this committee shall, at least thirty days before the annual meeting, send to the Secretary the names of nominees for the offices falling vacant under the rules. In addition to such regularly appointed committee, any other five members or associates, not in arrears, may constitute an independent Nominating Committee, and may present to the Secretary, at least thirty days before the annual meeting, all the names of such candidates as they may select. All the names of such independent nominees shall be placed upon the ballot list, with nothing to distinguish them from the nominees of the regular committee, and the Secretary shall at once mail the said list of names to each member and associate in the form of a letter ballot, it being understood that the assent of the nominees shall have been secured in all cases.

ART. 32. In the election of Vice-Presidents, each member and associate may cast as many votes as there are Vice-Presidents

to be elected. He may give all these votes to one candidate, or distribute them among more, as he chooses. Managers shall be voted for in the same way.

ART. 33. Any member or associate entitled to vote may vote by retaining or changing the names on said list, leaving names not exceeding in number the officers to be elected, and returning the list to the Secretary—such ballot enclosed in two envelopes, the inner one to be blank and the outer one to be endorsed by the voter. No member or associate in arrears since the last annual meeting shall be allowed to vote until said arrears shall have been paid.

ART. 34. The said blank envelopes shall be opened by tellers at the annual meeting, and the person who shall have received the greatest number of votes for the several offices shall be declared elected.

MEETINGS.

ART. 35. The annual meeting of the Society shall be held on the first Tuesday in December of each year, in the City of New York, unless otherwise ordered, at which a report of proceedings and an abstract of the accounts shall be furnished by the Council. The Council may change the place of the annual meeting, and shall, in that case, give timely notice to members and associates.

ART. 36. Other regular meetings of the Society shall be held in each year at such time and place as the Council may appoint. At least thirty days' notice of all meetings shall be mailed by the Secretary to members, honorary members, associates, and juniors.

ART. 37. Special meetings may be called whenever the Council may see fit; and the Secretary shall call a special meeting at the written request of twenty or more members. The notices for special meetings shall state the business to be transacted, and no other shall be entertained.

ART. 38. Any member, honorary member, or associate, may introduce a stranger to any meeting; but the latter shall not take part in the proceedings without the consent of the meeting.

ART. 39. Every question which shall come before the Society shall be decided, unless otherwise provided by these rules, by the votes of a majority of the members and associates present, provided there is a quorum.

ART. 40. At any regular meeting of the Society thirteen or more members and associates shall constitute a quorum.

ART. 41. Unless otherwise ordered, papers shall be read in the order in which their text is received by the Secretary. Before any paper appears in the *Transactions* of the Society, a copy of the paper shall be sent to the author, and, so far as possible, a copy of the reported discussion shall be sent to every member who took part in the same, with requests that attention shall be called to any errors therein.

ART. 42. The Society shall claim no exclusive copyright in papers read at its meetings, nor in reports of discussions, except in the matter of official publication with the Society's imprint, as its *Transactions*. The Secretary shall have sole possession of papers between the time of their acceptance by the Publication Committee and their reading, together with the drawings illustrating the same; and at the time of such reading, or as soon thereafter as practicable, he shall cause to be printed, with the authors' consent, copies of such papers, "subject to revision," with such illustrations as are needed for the *Transactions*, for distribution to the members and for the use of technical newspapers, American and foreign, which may desire to reprint them in whole or in part. The policy of the Society in this matter shall be to give papers read before it the widest circulation possible, with the view of making the work of the Society known, encouraging mechanical progress, and extending the professional reputation of its members.

ART. 43. The author of each paper read before the Society shall be entitled to twelve copies, if printed, for his own use, and all members shall have the right to order any number of reprints of papers at a cost to cover paper and printing; *provided*, that said copies are not intended for sale.

ART. 44. The Society is not, as a body, responsible for the statements of fact or opinion advanced in papers or discussions, at its meetings; and it is understood that papers and discussions should not include matters relating to politics or purely to trade.

ART. 45. These rules may be amended, at any annual meeting, by a two-thirds vote of the members present; *provided*, that written notice of the proposed amendment shall have been given at a previous meeting.

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PAPERS

OF THE

NEW YORK MEETING

(XLIId)

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

DECEMBER 4th TO 7th, 1900.

BEING ALSO THE TWENTY-FIRST ANNUAL MEETING OF THE SOCIETY

No. 867.

PROCEEDINGS

OF THE

NEW YORK MEETING

(XLIId)

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

December 4th to 7th, 1900.

THE twenty-first Annual Meeting of the Society was also its Forty-second Convention, and was held in New York City at the house of the Society and its Library, between the dates of Tuesday, December 4th, and Friday, December 7th.

The opening session on the evening of Tuesday was scheduled for nine o'clock, but members began to gather at an earlier hour in considerable numbers. The President for the year, Mr. Charles H. Morgan, of Worcester, Mass., called the meeting to order in the crowded auditorium and announced the appointment of Messrs. G. W. Weeks, P. M. Chamberlain, and Harrington Emerson as a Committee of Tellers, to open and count the votes cast for the several offices to be filled at this meeting under the provisions of Articles 31 and 34 of the Rules. He then proceeded to deliver the presidential address, to which he had given the title of "Some Land Marks in the History of the Rolling Mill," which was illustrated with lantern slides and was listened to with profound attention.

At the close of the paper and its illustrations, a light luncheon was served in the room below, and the members remained until a late hour for social reunion.

Second Day. Wednesday Morning, December 5th.

The second or Business Session of the Annual Meeting was called to order this morning at ten o'clock. The custom of the Society which has prevailed for so many years was still continued, of asking the members in attendance to register their names on arrival. At the time of such registration they received a convention badge bearing a number which was the same as the line of the convention register which bore their signature. By combining with this plan of numbered badges the issue at frequent intervals of printed copies of the register, the members in attendance at the meeting were advised of the names of members and could easily identify those whom they wished to meet by the number of the badge, even if face or name might have been uncertain to them. It was generally observed that upon its social side the renewal of old acquaintanceships and the formation of new ones began at once from the opening session, almost as if intercourse had been unbroken from the date of the convention a year ago. The register showed the phenomenal and unprecedented total registration of 759, of which 469 were officially enrolled members of the Society. The balance in registration was made up of ladies and other guests in attendance during the meeting. The following list contains the names of members only:

Ackerman, W. S.
Adams, E. T.
Alberger, Louis R.
Albree, Chester B.
Alden, Geo. I.
Aldrich, H. L.
Almond, T. R.
Almy, Darwin.
Ames, W. L.
Andrews, Wm. J.
Armstrong, E. J.
Arnold, G. Le H.
Ashley, Frank M.
Ashworth, A. K.
Ashworth, Daniel.
Atwater, C. G.
Aue, Jos. E.
Bacon, Geo. W.
Bagg, S. F.
Bailey, T. S.
Bailey, W. H.
Baker, Chas. Whiting.
Baldwin, Stephen W.
Ball, B. C.
Ball, F. H.
Bang, Henry A.
Bardwell, A. F.
Barnay, J. M.
Barr, Harry P.
Barr, John H.
Bartol, Geo.
Basford, G. M.
Bates, E. P.
Beach, Chas. S.
Beach, G.
Belcher, A. W.
Bell, Jos. M.
Benns, C. P.
Billings, Chas. E.
Binsse, Henry B.
Bird, John D.
Boies, H. M.
Bole, Wm. A.
Bolton, R. P.
Bond, Geo. M.
Bowen, E. S.
Bowman, A. L.
Boyd, John T.
Boyer, E. S.
Boyer, Francis H.
Bradley, W. H.
Bragg, C. A.
Brashear, Jno. A.
Briggs, T. H.
Bristol, Wm. H.
Brown, Frank G., Jr.
Brown, Robt. S.
Brown, Wm. Clinton.
Bruegel, A. T.
Bulkley, Henry W.

Bull, Gould H.
Bullard, E. P.
Bunnel, Sterling H.
Burchard, A. W.
Burditt, Wm. F.
Burnham, H. A.
Burns, A. L.
Burton, F. H.
Camp, Geo. E.
Carpenter, R. C.
Cary, A. A.
Cash, A. W.
Cassier, Louis.
Chamberlain, Paul M.
Chandler, C. A.
Chandler, Irving A.
Chapin, W. W.
Christensen, A. C.
Christie, W. W.
Close, R. T.
Cogswell, W. B.
Colby, Albert L.
Colvin, Fred H.
Comly, Geo. N.
Connell, J. A.
Conrad, H. V.
Coster, Edward L.
Cowperthwait, A.
Cox, J. D.
Craig, Jas., Jr.
Cremer, Jas. M.
Crosby, W. W.
Cullingworth, Geo. R.
Cummings, O. P.
Dale, O. G.
Dallett, W. P.
Daly, M. J.
Daniels, F. H.
Darbee, Wm.
Darling, Edw. A.
Darrin, David H.
Davey, Warren.
Davis, Daniel.
Davis, Robt. G.
Dean, F. W.
Deming, Wm. H.
Derbyshire, W. H.
Dewson, E. H.
Dinkel, Geo.
Dodge, Jas. M.
Doughty, W. F.
Ducommun, Ed.
Edwards, V. E.
Ekstrand, Chas.
Emerson, Harrington.
Emrie, Almon.
Engel, Louis G.
Ennis, W. D.
Evans, Ira N.
Evans, Q. N.
Faber du Fair, A.
Farwell, E. S.
Feldman, A. M.
Fellows, E. R.
Fernald, R. H.
Field, C. J.
Fish, C. H.
Fitch, Walter V.
Fladd, Fredk. C.
Flagg, Stanley G., Jr.
Fleming, W. R.
Flint, B. P.
Forbes, W. D.
Foster, E. H.
Foster, Pell W.
Fowler, Geo. L.
Fox, Geo. W.
Frank, Geo. Wm.
Freeman, J. R.
French, Lester G.
Frevert, H. F.
Frith, Arthur J.
Fritz, John.
Fulton, Geo. R.
Gabriel, W. A.
Gantt, H. L.
Garfield, L. M.
Geoghegan, Stephen.
Gibson, Geo. H.
Goetz, V. J.
Goetze, Fredk. A.
Goldsmith, N. O.
Gordon, H. D.
Goss, W. F. M.
Goubert, A. A.
Gould, W. V.
Graves, E.
Greenleaf, Geo. E.
Grimm, Paul H.
Grist, B. W.
Grohmann, Carl L.
Gunther, Chas. O.
Gwilliam, Geo. T.
Hale, Robt. S.
Hall, A. F.
Hall, F. A.
Hall, F. G., Jr.
Hall, Robt. E.
Halsey, F. A.
Hamilton, J. V.
Hammett, H. G.
Hanson, B. M. W.
Hardy, Geo. F.
Hartness, Jas.
Hawkins, John T.
Hayward, Henry S.
Heisler, Chas. L.
Henning, Gus C.
Henshaw, F. V.
Herbert, Fredk. D.
Herschmann, Arthur.
Heywood, W. A.
Hibbard, Henry D.
Higgins, Milton P.
Hill, Warren E.
Hill, William.
Hillard, Chas. J.
Hillman, G.
Holt, Frank E.
Honiss, Wm. H.
Hopton, L. R.
Hopton, W. E.
Horstman, H. J.
Horton, John T.
Hough, D. L.
Howell, E. I. H.
Hoxie, W. D.
Hulett, John.
Hunt, Chas. Wallace.
Hunt, Robt. W.
Hunt, W. F.
Hunter, Jas. D.
Hutton, F. R.
Hyde, Chas. E.
Idell, F. E.
Inglis, Jas.
Jacobus, D. S.
Jefferies, F. L.
Jenkins, M. C.
Jenks, L. Howard.
Jennings, E. L.
Johnson, Arthur E.
Johnson, Wallace C.

Jones, Forrest R.
Jones, H. K.
Jones, Washington.
Jordan, S. S.
Kafer, Jno. C.
Katte, E. B.
Kaup, W. J.
Keep, Wm. J.
Kelsey, W.
Kent, Wm.
Kerr, C. V.
Kettell, Chas. W.
Kuhn, Jos.
Ladd, Geo. B.
Laforge, F. H.
Lane, H. M.
Lane, Harry M.
Lane, J. S.
Lange, P. A.
Lanza, Gaetano.
Lape, W. E.
Leland, Henry M.
Lewis, D. J.
Lewis, Jos. E.
Libby, Sam. H.
Lieb, J. W., Jr.
Lilley, Geo. H.
Lockwood, E. H.
Logan, Jno. D.
Longnecker, Chas. K.
Longstreth, Chas.
Loomis, F. J.
Lord, H. F.
Lorenz, Wm. A.
Loring, Chas. H.
Louer, L. S.
Loveland, J. W.
Low, F. R.
Lowell, J. Welch.
Loyd, John.
McBride, Jas.
McFarland, W. M.
McKee, J. J.
McKlever, W. H.
MacLaren, M. N.
Main, Thos. J.
Manning, Chas. H.
Mason, D. A.
Mason, W. B.
Matlack, J. R., Jr.
Mattice, A. M.
Mayo, W. B.
Meats, Jno. T.
Meier, E. D.
Mellin, C. J.
Meyer, H. C, Jr.
Middleton, Percy H.
Miller, Fred J.
Miller, J. S.
Miller, Spencer.
Moeller, Franklin.
Moldenke, R. G. G.
Monaghan, Wm. F.
Moore, D. G.
Moore, M. F.
Morgan, Chas. H.
Morgan, Paul B.
Morris, Henry G.
Moulthrop, Leslie.
Muller, T. H.
Nagle, A. F.
Nash, L. H.
Nason, Carleton W.
Neff, E. H.
Newcomb, Chas. L.
Newhall, J. B.
Ninde, Wm. E.
Norris, Jno. H.
Odell, W. H.
Olin, F. W.
Otis, Spencer.
Owens, R. B.
Parker, A. W.
Parks, E. H.
Parsons, F. W.
Parsons, W. E.
Paterson, A. W., Jr.
Patitz, A. M.
Patton, J. H.
Paul, John W.
Peek, Geo. M.
Peirce, Wm. H.
Pell, H. S.
Penny, Edgar.
Pentz, A. D.
Perry, S. B.
Phelps, F. A.
Phillips, Franklin.
Pitkin, S. H.
Platt, John.
Pomeroy, H. D.
Poore, J. B.
Porter, Chas. T.
Pratt, Chas. R.
Prellwitz, Wm.
Pryor, Fredk. L.
Raymond, Ralph.
Read, Carleton A.
Rearick, Chas. B.
Reeves, Clifton.
Reist, H. G.
Rice, Arthur L.
Rice, C. W.
Rice, Richard H.
Richards, C. R.
Richards, Francis H.
Richards, Frank.
Richmond, Geo.
Ridsdale, T. W.
Riesenberger, Adam.
Rites, F. M.
Robb, D. W.
Robinson, A. W.
Robinson, Cyrus.
Robinson, John M.
Rockwood, Geo. I.
Roe, Mark W.
Roelker, H. B.
Rogers, W. S.
Rohrer, A. L.
Roney, Wm. R.
Ross, Chas. E.
Rowland, Chas. B.
Rowland, Thos. F.
Rowland, Thos. F., Jr.
Sabin, A. H.
Sando, Will J.
Sangster, Wm.
Sanguinetti, Percy A.
Sargent, C. E.
Sattler, W. R.
Schaeffler, Jos C.
Scheele, J. M. B.
Scheffler, Fredk. A.
Schnuck, Edw. F.
Schoenborn, W. E.
Scholl, Julian.
Schumann, F.
Schwamb, Peter.
Schwanhausser, Wm.
Scott, Seaton M.
Sederholm, E. T.
Sedgwick, E. H.

Seymour, J. A.
Shantz, Oliver S.
Shaw, T. Jackson.
Shelmire, W. H., Jr.
Shipley, Thos.
Sims, Gardiner C.
Sinclair, Angus.
Slater, A. B., Jr.
Smith, Albert W.
Smith, Eph.
Smith, Jesse M.
Smith, J. Waldo.
Smith, Oberlin.
Snell, Henry I.
Sornborger, E. C.
Soule, R. H.
Souther, Henry.
Spangler, H. W.
Sparrow, E. P.
Spies, Albert.
Spilsbury, E. G.
Stangland, B. F.
Stanwood, Jas. B.
Steele, W. D.
Stegmann, Geo. H.
Stetson, Geo. R.
Stillman, F. H.
Stutz, C. C.
Suplee, H. H.
Swasey, Ambrose.
Sweet, John E.
Tabor, Harris.
Taylor, J. T.
Taylor, W. M.
Thomas, Chas. W.
Thomas, E. W.
Thompson, Edw. P.
Thompson, S. K.
Thomson, John.
Thurston, R. H.
Tibbals, G. A.
Tompkins, S. D.
Torrance, Henry, Jr.
Torrance, Kenneth.
Torrey, H. G.
Townsend, David.
Trautwein, A. P.
Tremaine, E. G.
Trump, Chas. N.
Trump, Edw. N.
Tucker, Edwin D.
Turner, John.
Tuska, G. R.
Tuttle, Willard S.
VanDerhoef, Geo. N.
Varney, W. W.
Verastegui, A. de.
Waitt, A. M.
Waldron, F. A.
Wallace, J. H.
Walworth, Arthur C.
Ware, Justin A.
Warner, Worcester R.
Warren, B. H.
Washington, W. D. H.
Watson, Wm.
Webber, S. S.
Webber, Wm. O.
Weber, F. C.
Weber, Geo. A.
Webster, Hosea.
Webster, Wm. R.
Weeks, Geo. W.
Wellman, Chas. H.
Wellman, Saml. T.
Wells, J. Leland.
Wheeler, F. Meriam.
Wheelock, Jerome.
Whinery, S.
White, Maunsel.
Whitney, Marshall L.
Widdecombe, R. A.
Wilcox, John F.
Wiley, Wm. H.
Williams, Franklin.
Williams, T. H.
Williston, A. L.
Wilson, J. Fred.
Wilson, W. R.
Winship, Jas. G.
Winther, Chas. A. G.
Wood, E. E.
Wood, F. J.
Wood, M. P.
Woodbury, C. J. H.
Woolson, O. C.
Woolson, W. D.
Wright, Jas. K.
Wyman, H. W.
York, H. W.
Young, W. D.
Zehnder, C. H.
Zimmerman, Wm. F.

The first order of business was the Report from the Council to the general Society. It was read by the Secretary, as follows:

ANNUAL REPORT OF THE COUNCIL, FISCAL YEAR, 1899–1900.

The Council would present to the Society, convened for its twenty-first annual meeting, the report of business which has been before it for consideration during the Society year which is just closing.

The Council has held five meetings during the year.

Under the head of business referred to the Council by the

conventions has been the question of the appointment of a committee to investigate and report upon the proper way to consider the subject of the fair valuation of a water-power privilege. As the matter lay before the mind of the Council, it was its opinion that it was so difficult to separate the commercial and the legal questions attaching to this problem from those which were properly professional, that it could not be considered as one which should come conveniently under the purview of the Society, and that with the information at its hand it did not seem expedient to appoint the committee which was provided for in the resolution of the Society.

Invitations from important cities presented to the Society that it should designate the place for its approaching meetings have been carefully considered, but no definite action has been taken at the date of the preparation of this report. A proposition has been made that the Society should hold its spring meeting of 1901, at some convenient date, in the city of Buffalo, so as to be in attendance at the same time at the Pan-American Exposition, to be held in that city, beginning May 1st.

The Council has considered very carefully the question as to the wisdom of enlarging the Society accommodations at its present site. It has been the sense of the Council that for the present, at least, it was not desirable to take action along these lines. The Council has, therefore, taken active steps to provide a more satisfactory arrangement for ventilating the Society's auditorium, and for the heating of the house as a whole, than was possible with the hot-air furnaces and the natural-draft system, upon which dependence has hitherto been laid. A committee of the Council was appointed to consider this subject and obtain estimates and report. As the result of the work of this committee, a forced-draft system, with electric fan and heating coils, has been installed during the summer, and will be in active service during the convention and at other times. The contractors for this work were Messrs. Baker, Smith & Co., of New York City. Attention of the members is invited to the mechanical details of the plant and its operation.

Early in the winter succeeding the last annual meeting, steps were taken to ascertain whether a sufficient number of members of the Society could be gotten together at one time, with the purpose of visiting England and France in a body, to make it possible to secure a steamer for the use of the Society, to the

exclusion of other passengers. It will be remembered that this was a feature of the party which visited England during the period of the Paris Exposition of 1889, and the plan had much to commend it at that time. The result of persistent inquiry brought out the fact that no party of a size sufficient to warrant the exclusive use of a transatlantic steamer could be gotten together for any one date of sailing. It was thereupon left for each person proposing to make the European trip to arrange for his own details of transportation, and the Council and the Society satisfied itself in appointing an Executive Committee from among those who were to constitute that European party, who should attend to the details and necessary organization incident to courtesies arranged for the American engineers by the sister societies of Great Britain. This Executive Committee consisted of Messrs. Charles H. Morgan, chairman; H. H. Suplee acting as secretary of the committee, with whom were associated Messrs. William H. Wiley, Jesse M. Smith, members of the Council, and Mr. James Dredge, of London, honorary member of the Society. The committee, by the courtesies of the "Engineering Magazine"—extended through Mr. John R. Dunlap, its proprietor—were permitted to make use of the London offices of that journal as a central office for the transatlantic party, and all the courtesies which were extended to the American engineers passed through the channel of the London office of the committee. This arrangement was most satisfactory and convenient, and the Council has extended a proper vote of thanks to Mr. Dunlap for the courtesies which the members individually, and the Society as a body, enjoyed at his hands.

The Executive Committee will make a report of the incidents of the British, French, and German visits, as a feature of the business of the annual meeting, which will follow the report of the Council, as an appendix thereto. The Council would report that, by reason of the courtesies which have been enjoyed by the Society and its members at the hands of the three great engineering societies—the Institution of Mechanical Engineers of Great Britain, the Institution of Civil Engineers of Great Britain, and the Society of Civil Engineers of France—the presidents of those societies, in office during the summer of 1900, have been duly proposed for honorary membership in the American Society of Mechanical Engineers, and their election to this honor is hereby made public. Mr. John Fritz has been duly proposed and elected

for honorary membership in the Society, in accordance with its rules.

Mr. Gus C. Henning was authorized in the Spring to attend a council meeting of the International Association for Testing Materials, held in Zurich, Switzerland, and an appropriation was made to cover in part the expenses of his journey.

The Council has been requested by the management of the proposed Engineering Congress, to be held in August, 1901, in the city of Glasgow, Scotland, to appoint representatives upon a general committee, which should include both Americans and other engineers. This Society was requested to be the channel for communicating this desire to the other American societies. By direction of the Council, twelve representative engineers have been nominated, and our delegates are Messrs. S. T. Wellman, C. H. Morgan, George W. Melville, Sir Benj. Baker, James Dredge, W. C. Unwin, H. F. Parshall, Philip Dawson, Bryan Donkin, H. F. L. Orcutt, O. H. Baldwin, and Alex. Sahlin.

The Society has received from Mr. Gustave Eiffel, of Paris, an elaborate monograph descriptive of the great tower of 300 metres. This book has been put in the library, and proper recognition has been sent to its distinguished author.

The Verein Deutscher Ingenieure, through its secretary and council, have requested from this Society its coöperation in the preparation of a technical dictionary, which should contain words and definitions in German, English, and French. The Council directed that, in response to this invitation, the coöperation of the Society would be given to the extent of placing the editor in communication with specialists, members of the Society, in various lines, who may be able to assist in the desired work, provided that this Society be not involved in any expense other than that included in the necessary correspondence.

The Society has been requested to coöperate with certain other national bodies, to secure the establishment of a National Standards Bureau, in connection with the United States Office of Standard Weights and Measures, which should be made a central point for the calibration and standardization of scientific and engineering apparatus. The Council has accepted this invitation by appointing Mr. Jesse M. Smith the chairman of such a committee, but has not completed the full appointment at the date of the preparation of this report.

The increasing use by the members of the Society of the facilities of the Society house has made it necessary to introduce into the management of its affairs a little more formality and system than has hitherto prevailed. The committee known as the Library and House Committee has been instructed to prepare and enforce certain house rules, which are to go into action on December 1, 1900, and which will be made public through the channels of the Society circulars.

It has been the sense of the Council that it would be desirable to discontinue the Society's Committee on Standard Methods of Tests and Testing Materials, for the present, at least. This proposition having been concurred in by certain members of the committee who have been most active in the work which the committee has done, the Council has directed that this step be taken and the committee be discharged with the thanks of the Council for its labors in the previous years in which the committee has been in existence.

The Council would call the attention of the members to certain statements in the report of its Finance Committee, which announces to the membership that, by virtue of the prosperity of the Society during the ten years between May, 1890, and July 1, 1900, it has become possible to pay off and cancel the second mortgage of $32,000, which was held by a trust company as trustee for the members of the Society, who took bonds issued at that time to make the cash payment required for the purchase of the Society house. The redemption of these bonds has been mainly by the purchase of them, on behalf of the Council, from their holders among the membership. On July 1st, upon the transfer to the trust company of the entire issue of bonds, the mortgage was cancelled and a satisfaction piece was filed and recorded, so that the only obligation outstanding against the house is the first or purchase money mortgage of $33,000. It is the purpose of the trustees of the Library Association, who are the owners of the real estate, that, pursuant to an arrangement made with the holder of that first mortgage, it shall be reduced as the accumulations of the next succeeding years may make possible.

The Council would report for record in its Transactions the following list of deaths since the publication of its annual report in December, 1899:

Louis S. Wright, December 29, 1899; John L. Wilkinson,

January 16, 1900; Jos. P. Mullen, January 29; Geo. H. Norman, February 4; W. E. Ward, March 2; H. G. Geer, March 7; A. C. Rand, March 9; W. B. Roberts, April 9; Salvador Potis, April 17; Fred. W. Wood, May 19; J. G. A. Meyer, July 16; Winthrop Thayer, July 18; James Hemphill, August 7; John F. Allen, October 2; James H. Bowden, November 17; Chas. A. Dixon, December 22.

The Council would report the following summary of the membership of the Society at the annual meeting of the Society, December, 1900. The list contains the names of those who have been elected preceding this meeting and excludes those who by persistent failure to pay the dues of the Society have allowed their membership to lapse.

Honorary Members	19
Members	1,506
Associates	143
Juniors	464
Total	2,132

Respectfully submitted,
By the Council.

The Council would submit the Report of its tellers, as follows:

REPORT OF TELLERS.

The undersigned were appointed a committee of the Council to act as tellers, under Article 11 of the Rules, to scrutinize and count the ballots cast for and against the candidates proposed for membership in their several grades in the American Society of Mechanical Engineers, and seeking election before the XLIId meeting, New York, 1900.

They have met upon the designated day, in the office of the Society, and have proceeded to the discharge of their duty. They would certify, for formal insertion in the records of the Society, to the election of the following persons, whose names appear on the appended list, in their several grades.

There were 496 pink ballots cast, of which 14 were thrown out because of informalities. The tellers have considered a ballot as informal which was not endorsed.

Charles H. Loring,
George Richmond,
H. H. Suplee,
Jesse M. Smith,
} *Tellers of Election.*

AS MEMBERS.

Boehm, Wm. H.
Bruegel, A. T.
Carroll, E. H.
Feldman, A. M.
Foote, A. W.
Fox, Chas. H.
Fox, Wm.
Hanson, B. M. W.
Hardie, Wm.
Herbert, Chas. G.
Johnston, Wm. T.
Kimball, D. S.
Kohler, D. S.
Land, Frank.
Lane, Henry M.
Libby, Chas. L.
Lilley, G. H.
Love, Wm. S.
McElroy, Jas. F.
McLaren, Daniel.
Mayo, Wm. B.
Moldenke, R. G. G.
Pajeken, J. F.
Palmer, A. C. H.
Peabody, E. H.
Pierce, Chas. D.
Powell, Jas.
Rice, C. W.
Robb, Wm. L.
Robinson, Chas. S.
Ross, Chas. E.
Rugan, H. F.
Ryding, H. C.
Scott, Joseph A.
Snyder, F. T.
Stevenson, Wm. A.
Stranahan, O. A.
Trube, G. A.
Voorhees, G. T.
Wais, Chris.
Wille, H. V.
Weed, E. E.
Yont, Chas. A.
Young, Walter D.

AS ASSOCIATES.

Aldrich, H. L.
Bechtel, Jno. A.
Bogardus, Wm. B.
Davis, F. H.
Deeds, Edward A.
Lane, Francis W.
Wheildon, W. M.
Wieselgreen, C. E.
Williams, A. F.

PROMOTION TO FULL MEMBERSHIP.

Corey, Fred. B.
Patitz, J. F. M.
Peek, Geo. M.
Read, C. A.
Watson, Henry D.

AS JUNIORS.

Abell, H. C.
Alford, L. P.
Barnard, W. N.
Brown, Jas. M.
Brown, J. R.
Capron, S. A.
Claroge, E. D.
Cluett, A. E.
Fitch, W. V.
Gibson, G. H.
Gould, N. J.
Gunther, C. O.
Hamilton, A. K.
Harrington, H. G.
Hayward, H. S., Jr.
Hiles, E. K.
Hill, Ebenezer, Jr.
Hutchinson, Geo. A.
Jamison, A. P.
Kelsey, Walter
Melville, L. B.
Miller, J. S. K.
Miner, M. H.
Moore, S. H.
Morrison, Wm.
Nicklin, E. W.
Perkins, Geo. H., Jr.
Roe, M. W.
Rowe, C. W.
Raymond, Ralph.
Schaeffler, J. C.
Sumner, H. W.
Turner, Wm. Payson.
Van Dervort, A. O.
Van Zandt, Paul C.
White, Jas. Alfred
Whitted, Thos. B.
Woodard, L. A.
Woodwell, J. E.
Young, E. R. D.
Young, Jno. T.

At the close of the Report of the Council, the second order of business was the Report of the Finance Committee, which was as follows:

ANNUAL REPORT OF THE FINANCE COMMITTEE OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, 1899-1900.

For the fiscal year 1899-1900 the Finance Committee of the American Society of Mechanical Engineers would respectfully

report to the Council and the Society the following statements of receipts and expenditures which have passed under its direction on behalf of the Society during the year beginning November 15, 1899, and ending November 12, 1900.

Secretary's Balance sheet for the fiscal year ending November 12, 1900:

Dr.		Cr.	
To Receipts for the Year....	$42,452 78	By Cash to Treasurer.....	$42,452 78

Itemized statement of receipts and expenditures of the Society for the fiscal year 1899-1900:

Receipts.

Dr.		
Initiation Fees.....		$4,610 50
Dues { Current.. $25,172 23		
Dues { Past..... 1,473 55		26,887 97
Dues { Advance. 242 19		
Sales of Publications.....		2,216 35
Binding		32 00
Engraving		459 02
Life Membership (cash).....		2,200 00
Interest on Investment.....		1,352 50
Office Expenses.....		6 66
Postage and Express.....		87
Hall Rentals.....		1,097 50
Room "		1,803 42
Badges and Certificates.....		936 25
Lighting.....		5 00
Check Collection Charges....		2 62
Meetings (subscriptions from members)*.....		842 06
Rent, Interest, and taxes....		06
Total Receipts.....		$42,452 78
Cash in Treasurer's hands the first of year.....		100 92
Total.....		$42,553 70
Cash in Treasurer's hands, first of year 1900-1901, forward		248 07

Disbursements.

Cr.	
Reprints and Publications...	$9,496 61
Postage and Express.... ...	2,920 38
Office Expenses	380 20
Salaries.....	8,153 00
Engraving.....	1,599 30
Contingencies (profit and loss)	73 60
Binding *Transactions*.... ...	1,743 15
Meetings †	2,489 61
Work of Committees.....	341 90
Badges and Certificates.....	1,064 02
Travelling.....	150 00
Insurance and Safe Deposit...	17 00
Rent, Interest, and Taxes....	4,661 45
Printing — Circulars, Catalogues, Office Forms, etc..	3,682 96
Stationery Supplies	274 18
House Supplies and Furniture	614 25
Library (book purchase and binding).....	1,407 95
Janitorial Supplies.....	147 25
Fuel.....	23 00
Lighting (gas and electric light).....	423 98
Laundry	361 70
Repairs to House, Furniture, etc	537 98
Interest on Investment.....	20 00
Collection out-of-town checks	22 16
Total regular Disbursements.....	$40,605 63
Investment, M. E. L. A. bonds bought.....	1,700 00
Total.....	$42,305 63
Cash on hand to balance....	248 07
Total.....	$42,553 70

* This was the amount subscribed by members toward the cost of the reception at the New York meeting of 1899.

† The cost of the reception was $905, which amount is included in the total amount expended for meetings, as shown on credit side above.

At the time of this report there remain outstanding uncollected accounts due the Society at the end of the year 1899–1900 as follows:

From Members, Dues, etc.

3 men owe for initation fee		55 00
69 " " " the year 1899–1900, just closed, at $15		1,035 00
19 " " " " " " " " " $10		190 00
39 " " " dues from 1 to 5 years back		1,513 35
1 man owes for 9 years and a balance back dues owing to the fact that on account of his geographical location he cannot remit		140 98
7 men owe small balances for pamphlets, badges, volumes, etc		20 18
Total, 138 men (about 6 per cent. of the membership)		$2,954 51

From Miscellaneous Accounts.

1 society owes for hall rent	$25 00	
13 persons owe for room rent	87 17	
5 " " " papers	1,068 35*	
Total from 19 persons		1,180 52
Total amount outstanding and uncollected		$4,135 03

Due to the action which has been taken by the Council, under Art. 19 of the Rules, on such men as owed a number of years' back dues and from whom the Society seemed to be able to get no satisfactory and definite responses to statements and letters sent them, the sum shown above as due the Society at the end of the year 1899–1900—*i.e.* $4,135.03—is practically all collectable and the larger portion of it will without doubt be collected during the new year.

ASSETS AND LIABILITIES.

At the end of the year 1899–1900.

Exclusive of such property as pamphlet copies of the papers, and of office and house furniture, etc., which is also owned by the Society.

Assets.

Interest in property at 12 West 31st Street, New York	$29,000 00
Stock of bound and paper covered copies of the *Transactions* of the Society, Vols. I.–XX. inclusive, on hand, estimating them at the price at which they are sold to members	24,000 00
Outstanding indebtedness due Society as itemized above	4,135 03
Cash on hand in bank, as reported above	248 07
Total assets	$57,383 10

* Of this amount $1,067 is owed by one well-known firm for pamphlets recently furnished them and the balance $1.35 from 4 persons for pamphlets.

The above statement of assets, moreover, does not include the stereotype plates of the volumes of the *Transactions*. It covers only the assets which are convertible under favorable conditions into cash. Nor does it include office furniture and fixtures in use.

The Society has as a liability at this date a running account with the firm which prints its *Transactions*, and will also soon have a liability for the cost of the new heating and ventilation plant that has been installed this summer though not fully completed at the time of this report, and also for the rewiring of the Society house, which was necessary by action of the Board of Fire Underwriters. These will be paid at once out of the receipts of the new year 1900-1901.

CANCELLING OF SECOND MORTGAGE ON SOCIETY HOUSE.

Those members of the Society whose membership antedates the fall of 1889 will no doubt remember that in that year the present home of the Society was bought for $60,000 by the Mechanical Engineers' Library Association, and that there have been two mortgages on the property. The second mortgage, amounting to $32,000, and covered by an issue of bonds for a like amount—which bonds were held by members—fell due July 1, 1900. The Finance Committee takes pleasure in announcing that that mortgage of $32,000 is now entirely wiped out; the bonds representing that sum having been acquired by the Mechanical Engineers' Library Association and the American Society of Mechanical Engineers, the former having acquired $3,000 and the latter $29,000 worth of the issue, thus giving the American Society of Mechanical Engineers an interest in the property to the amount of the latter sum. Steps will now be taken to reduce gradually the first mortgage which yet remains on the property. It may not be amiss to state that the property in the neighborhood of the Society house has gradually increased in value in the last ten years, so that our holding is now worth considerably more than what we paid for it in 1889.

MECHANICAL ENGINEERS' LIBRARY ASSOCIATION.

COPY OF THE ANNUAL REPORT OF THE TRUSTEES OF THE MECHANICAL ENGINEERS' LIBRARY ASSOCIATION, 1899–1900.

The summary of receipts and disbursements of the Trustees from November 15, 1899, to November 15, 1900, is appended.

Secretary's Balance Sheet, year 1899–1900:

Dr.		Cr.	
To balance on hand first of year	$250 68	By expenditure as itemized below	$5,315 40
To receipts as itemized below.	5,098 00	By cash on hand	33 28
	$5,348 68		$5,348 68
To cash on hand	33 28		

Itemized Statement of Receipts and Expenditures of the Association for fiscal year, 1899–1900:

Dr.		Cr.	
Receipts, Fellowship Fund	$117 00	Interest on mortgage	$1,402 50
" Sinking Fund	411 00	" " bonds	1,600 00
" Office Rent	4,500 00	Salaries	780 00
Interest on investment, 28 x $2.50 (30 bonds bought, but 2 had, July, 1900, coupons cut when purchased, being bought just before expiration)	70 00	Library and book purchase	4 80
		Stationery and printing	1 25
		Interest (coupons on bonds bought)	25 00
		Contingent	1 85
Total receipts for year	$5,098 00	Total expenditures	$3,815 40
Cash on hand first of year	250 68	Investment, bonds bought	1,500 00
	$5,348 68		$5,315 40
		Cash on hand	33 28
			$5,348 68
Cash on hand first of year, 1900–1901	$33 28		

All money due the Association at the end of this year (except $38, subscriptions from six men) has been paid, and all outstanding accounts against it are paid to date of this report.

ASSETS AND LIABILITIES.

Assets.

Cash on hand as above	$33 28	
House and lot, 12 W. Thirty-first Street, New York, N. Y.	65,000 00	
Furniture and equipment	5,000 00	
Books and manuscripts	10,700 00	
Subscriptions due by six men	38 00	
Total assets		$80,771 28

Liabilities.

First mortgage held by N. Y. Academy of Medicine	$33,000 00	
Equity in property at 12 W. Thirty-first Street, New York, held by Am. Soc. Mech. Engrs.	29,000 00	
Notes payable for six bonds bought from their original holders (6 x $100).....	600 00	
Total liabilities.....		62,600 00
Excess of assets over liabilities		$18,171 28

At the close of the reading of the printed report the President called for action to be taken on the work of the Society's professional committees during the year. These were mainly reports of progress.

The Committee on A Standard Method of Reporting Tests of Engines, stated through a letter from its Chairman, Mr. Francis H. Boyer, that their code was completed for the steam-engine section, and part of that which they proposed to present as to the testing of internally fired engines was in hand. It required, however, to be submitted for approval to the British member of the Committee, Mr. Bryan Donkin, and the Committee hoped that by the Spring Meeting of 1901 the document would be completed and ready for presentation and discussion.

The Committee on Standard Proportions for Parts and Threads of Pipe Unions, reported through its Chairman, Mr. E. M. Herr, by letter, that a full set of designs had been proposed for sizes running from one-eighth inch to four inches, based in the belief of the Committee upon well-considered principles, in which the standard both of the user and of the manufacturer had been thoroughly considered. In view of the fact that this subject had been first brought up by the American Railway Master Mechanics' Association, from which a Committee had been appointed and was engaged in joint work with the Committee of this Society and with a similar Committee of the Master Car Builders Association, it had been thought best to agree at this time to report progress only, in order to permit of further and fuller conference with the above joint committees, and to secure, furthermore, the action of a number of representative manufacturers. The Committee hoped to present a full report for discussion at the Spring Meeting of 1901.

The Committee appointed by the Council to conduct gatherings of members and their friends at stated monthly reunions,

under the control of a Committee of Junior Members, reported through its Chairman, Mr. Henry C. Meyer, Jr., as follows:

Report of Junior Committee.

Since the Committee reported at the Cincinnati Meeting, one very successful Junior Meeting has been held, at which the attendance was about 60. This occurred on Tuesday evening, October 13th. Mr. John C. Wait presented a paper upon "The Laws of Construction Contracts," in which a great interest was shown; the paper being followed by considerable discussion. The stenographer's report of the meeting is on file at the Society's rooms, and can be examined upon application. Mr. Wait will deliver a second lecture upon the same subject at a meeting to be announced later.

Mr. Cornelius Vanderbilt was scheduled to read a paper upon "Locomotive Fire-Boxes" at the October meeting, but on account of his failure to receive certain data that he had been promised, a postponement was necessary. It is expected that this paper will be read at one of the meetings in the near future. This report is made by the Chairman of the Committee in the absence of Mr. Frothingham, the Secretary.

The President then called for a report from the Society's Committee intrusted with the detail of erecting in Trinity Churchyard a suitable memorial to Robert Fulton. Mr. Gus C. Henning, Chairman of the Committee, made a verbal report, as follows:

Mr. Gus C. Henning.—The Committee can report that there is now definitely promised the sum of $1,450 towards the sum of $2,000 or $2,500 which the Committee had fixed as its limit. These subscriptions, however, have been received from less than 10 per cent of the total membership. The Committee believe that for the larger sum a monument could be erected which would have sufficient dignity to be fittingly representative of the Society, and the great engineer whom it is intended to honor. The members who were present at the meeting a year ago when the Committee made its first report, will recall that the Trinity Church Corporation has proposed to give to the Fulton Memorial of our Society one of the most prominent sites of the churchyard, near the front at the Rector Street side, opposite the present Livingston vault, in which the body of Mr. Fulton rests at present. We have several designs and estimates and intend to obtain others

within a few days, and will then know positively the minimum sum which will be required. I may add, furthermore, that the Committee hopes to receive from a group of its members concerned with one of its recent conventions the balance of $250, which was left over in the hands of the Committee of Arrangements when all their expenses connected with the meeting had been fully met. The Committee hopes at this meeting some who have not as yet contributed will take occasion to help in completing the necessary fund.

The Committee which had been appointed by the Council to take care of the detail incident to the courtesies to be shown to the Society during their visit to England and France in a somewhat organized way, during the summer of 1900, reported through its Secretary, Mr. H. H. Suplee. Mr. Suplee spoke of the purpose of the Committee to prepare for publication in the *Transactions* of the Society a somewhat formal report, that the exceeding courtesies shown to the Society on the occasion of this visit might be a matter of permanent and official record. Such report will be regarded as a paper of the current annual meeting, but there had not been opportunity to do the necessary work upon it in advance of the date of the meeting.

He called attention to the fact that the excursion of 1900 differed from the previous similar experiences of 1889, in that it had been found impossible to assemble the party on this side of the ocean with a view to crossing in one body. The various members chose their own steamer, and by appointment they met for organization at the house of the Institution of Mechanical Engineers of Great Britain by invitation of that body, on June 5th. During the week of the spring meeting of the British Society, all members who had attached themselves to the informal organization provided for at that meeting, were entertained in a delightful fashion of personal and official welcome, and were made joint partakers of the convention of the British Society, partaking in the discussion and joining in the excursions as guests of the convention.

The following week was that assigned for a general reunion at the house of the Institution of Civil Engineers of Great Britain, at which time and place all the visiting engineers in London, from the various American societies, were welcomed and most hospitably entertained. A conspicuous feature of that week was the reception of the American engineers and their English hosts

at Windsor, where the Presidents of the two societies, with their ladies, were personally presented to the Queen of England, and where the whole party received the full hospitality of the royal castle at Windsor.

Prior to the gatherings in London, the Society of Civil Engineers of France had requested that a limited number of delegates from this Society might be appointed to represent the Society at their reunion in Paris. The delegation appointed from among those who had already reached England and the Continent at the date of this meeting formed part of a large party —representatives of nearly all the engineering societies in the different parts of the world. The entertainment was most gratifying and acceptable, and the French Society, furthermore, arranged that the courtesies of their house, No. 19 rue Blanche, might be available for the American visitors all through the Exposition season. There was, furthermore, in addition to these official courtesies to the Society as a whole, and to its representatives, a most enjoyable trip organized by the firm of Messrs. Ludwig Loewe & Co., of Berlin. Those who could avail of this invitation became guests of the firm on their departure from Paris until the completion of the Berlin programme. The speaker's personal engagements had prevented him from taking part in the Berlin visit, but the reports of those who enjoyed it have been most glowing, and will be a feature of the formal document to follow.

The Council has directed that illuminated testimonials be presented in the name of the Society, signed by its President and Secretary, to the three societies. Beside the Institution of Civil Engineers and the Institution of Mechanical Engineers of Great Britain, and the Society of Civil Engineers of France, the firm of Ludwig Loewe & Co. is to be included in this action. These illuminations are now in preparation and will be transmitted to the hosts of the party early in the year. A record enrollment signed by the visitors was kept in the office of the Executive Committee, and in its final form will be accessible in detail to all interested. The members will have noticed in the Report of the Council, the action of that body in making the Presidents of the three European societies for the current year Honorary Members of the American Society of Mechanical Engineers.

The President called at this time for the Report of the Society's Committee on the movement to Standardize Direct-connected

Generating Sets. The Committee was in session on the day upon which this report was called for, so that it was not ready at this time. As presented later in the meeting, it is inserted at this point for convenience of record. It was signed by Mr. James B. Stanwood, Chairman of the Committee.

REPORT OF COMMITTEE ON STANDARDIZATION OF ENGINES AND DYNAMOS.

Your committee on standardization of engines and dynamos desires to report that it is making extremely satisfactory progress in its work.

It has been in conference with members from a similar committee, appointed by the American Institute of Electrical Engineers, and with members of a committee on standardization from the Engine Builders' Association. The result of this conference was a practical agreement by these committees on the tentative report made by your committee at the May meeting of our Society in Cincinnati.

In relation to the standardization of the sub-base dimensions, a large amount of data has been collected, and one or two reasonable schemes for harmonizing them have been mapped out.

It is hoped at the meeting next spring that a complete report covering the entire ground can be submitted.

At the conclusion of the committee reports, the President asked for the action of the tellers appointed at the previous session last evening to open and count the letter ballot for officers of the Society. This report was read by the Secretary as follows:

REPORT OF TELLERS.

The committee of tellers appointed last evening to count ballots cast by the members for officers of the American Society of Mechanical Engineers, for the year 1900–1901, begs to submit the following report:

Total ballots cast	627
Ballots thrown out unsigned	14
Ballots thrown out signed with rubber stamps	5
Other informal ballots	1
Total informal ballots	20
Total ballots counted by tellers	607

Of the regular ballot counted by the tellers they would report the following result:

For President.

S. T. Wellman, of Cleveland	605
Scattering	2

For Vice-Presidents.

Arthur M. Waitt, New York	600
James M. Dodge, Philadelphia	608
Ambrose Swasey, Cleveland	607
Scattering	

For Managers.

W. F. M. Goss, Lafayette, Ind	607
DeCourcy May, Scranton, Pa	598
D. S. Jacobus, Hoboken, N. J	608
Scattering	1

For Treasurer.

William H. Wiley, New York	606
Scattering	1

Our count, therefore, shows the election of the regular nominees.

Respectfully submitted,

GEORGE W. WEEKS,
HARRINGTON EMERSON,
PAUL MELLEN CHAMBERLAIN.

The President thereupon asked Mr. S. T. Wellman, President-elect, if he would accept the honor conferred upon him by the action of the voting membership. Upon receiving Mr. Wellman's affirmative reply, Messrs. Robert Hunt and Worcester R. Warner were requested, as an escort committee, to conduct the President-elect to the platform. President Morgan then extended to his successor the right hand of fellowship, and bespoke for him the courtesies which he had enjoyed from the members of the Society during his term about to close. Mr. Wellman in fitting reply expressed his sense of the honor that he should be called to fill the chair which had been occupied by such eminent engineers, and thanked the Society for the honor which had been done to him.

The Secretary read a courteous letter of invitation from Mr. John Thomson, President of the Engineers' Club of New York, inviting the members to be the guests of the club during the

meeting, and putting the privileges of the club at the service of such as would apply to designated members of the reception committee for the necessary cards. The Secretary further reported, that, by the courtesy of the "Locomobile" Company of America and the De Dion Bouton "Motorette" Company, arrangements had been made to have a considerable number of steam-carriages and a gasolene "Motorette" at the service of the members, and that parties for rides in these horseless carriages propelled by steam and gasolene could be made during the morning and afternoon of Wednesday, and that if it were found desirable this feature of the meeting could be extended to include Thursday, also. A considerable number availed themselves of the courtesy and attention evidenced by the presence of these carriages, in spite of the chilling wind and gray sky.

Mr. Arthur Herschmann, Mechanical Engineer of the Adams Express Company, presented an invitation that the members should view the three-ton express-wagon, propelled by steam, with which that company was experimenting. The members might visit the wagon at the company's station at Forty-ninth Street and Park Ave., and at the Friday morning session Mr. Herschmann had the wagon on exhibition on the street in front of the Society house.

Professional papers were then taken up as follows:

The paper by Mr. H. de B. Parsons, entitled "Comparison of Rules for Calculating the Strength of Steam Boilers," was discussed by Messrs. Rockwood, Cary, E. P. Thompson, Hale, Spangler, Kent, Snell, and Robb on its technical side, and finally, on motion of Mr. Rockwood, the following motion was put:

Resolved, that the Council be requested to consider the expediency of the appointment of a committee to review the various rules for proportioning the parts of steam boilers, and if in their opinion the appointment of such a committee would be desirable, that the Council have power to appoint such a committee.

This motion being seconded by Mr. Laforge, it was put by the Chair and unanimously adopted.

Mr. Charles T. Porter's paper, "A Record of the Early Period of High-Speed Steam Engineering," was presented by its author by title, and discussed by Messrs. Thurston and Suplee. Professor Thurston's paper closed the session. It was entitled "The Steam Turbine; the Steam Engine of Maximum Simplicity and of Highest Thermal Efficiency." It was discussed by Messrs.

Sargent, Kent, Engel, Bolton, Platt, Emerson, Rockwood, Carpenter, Herschmann, Snell, and Wheeler.

The second session thereupon adjourned. A luncheon was served in a room underneath the auditorium, beginning at twelve o'clock, and a great majority of the members in attendance remained till after luncheon for the opportunity of social and professional reunion for which the afternoon was left free. This policy has been followed for many years at the New York conventions, with the view of leaving the members free to attend to their individual affairs, without filling the day so completely as to interfere with their personal needs in the matter of business appointments. Quite a number went out in parties in the locomobiles, and in Mr. C. J. Field's De Dion Bouton "Motorette."

Third Session. Wednesday, December 5th.

President Morgan was unable to take the chair on this evening at this session, so that Past President John E. Sweet called the meeting to order.

The papers for this session were as follows: By Mr. William Sangster, entitled "Note on Centrifugal Fans for Cupolas and Forges"; by Mr. F. W. Dean, entitled "Power Plant of the Massachusetts General Hospital"; by Reginald P. Bolton, entitled "The Construction of Contracts"; by Mr. E. T. Adams, entitled "An American Central Valve Engine." The discussion on these papers was participated in by Messrs. Snell, James McBride, F. V. Henshaw, George I. Rockwood, Bolton, Kent, C. J. H. Woodbury, F. A. Scheffler, E. A. Darling, William H. Bryan, Wells, A. M. Wait, and D. W. Robb.

Fourth Session. Thursday Morning, December 6th.

This session was convened, by invitation of the authorities of Columbia University, in the large lecture room which is a distinguishing feature of the Havemeyer Hall at Columbia University, 116th Street and Broadway. The committees in charge of the meeting had prepared a printed slip giving the methods of approach to the University by the various transportation lines, which contained also the programme and itinerary for a visit to the University departments, including the Mechanical Laboratories, the Power House, the Shops, and the Library in particu-

lar, with information concerning other departments in which individual members might be interested. The session opened at 10.30 with the reading and discussion of papers, and at half past twelve President Low of the University was invited to the meeting room, and made a brief address of welcome to the Society, which he couched in the following terms:

President Low.—Mr. Chairman and Gentlemen—I understood that I was to have the pleasure of shaking hands, as I hoped, with all of you, in the Trustees' room, but I did not know until just now that I might have the additional pleasure of saying a word of welcome to you as a body. It is a great pleasure to us at the University to have this visit from the Society of Mechanical Engineers. I suppose that I may fairly say that Columbia's relation to mechanical engineering is not altogether unlike that of the country whose name we bear, at least in its poetic form. The United States has entered upon the field of its triumph in mechanical engineering somewhat recently, and this University has entered on the field of instruction in mechanical engineering quite recently. I hope, however, that you will believe me when I say that we have entered upon it in the same spirit and with the same high ideals that the country has brought to bear upon the consideration of all the problems which the mechanical engineer has already faced and solved; and out of the triumphs of your past we find inspiration for our future. We have not such a past of our own to refer to; but we rejoice in what has been done in our sister universities and scientific schools in this direction, and from their past as well we find inspiration for the path in which we hope to tread. I am sure you will see that your branch of engineering has had much to do with our material equipment just as it stands. We shall have, therefore, the inspiration of gratitude to your art, if I may call it so, or your science, if you prefer, for the services which we hope to render in the future to the profession which you represent. In view of all these considerations, I am sure you may feel that this University, under the lead of your Secretary, who is our professor of mechanical engineering, will do all that it can to advance this subject here.

Having said this word, which is naturally suggested by your own chief interest, will you not let me also add to it a word of very warm welcome from the scholars of this University whose interests lie in other fields. It always seems to me one of the splendid things about a University, that no matter what may be

the intellectual interest of a man, no matter how assiduously he may follow that in his own field, he finds himself working side by side with other men whose interests are entirely different, but who are working just as hard as he in their own occupations. I think the effect of that circumstance must be broadening; it must help to make better men if it does not help to make better engineers. But I suspect that we all of us do our own part in life best when we thoroughly respect and sympathize with the efforts of others in the careers that they have chosen for themselves. It is for that reason, because the sympathy of every scholar we have goes out to you, that I feel at liberty, and not only at liberty, but I feel as it were, under instructions, to bid you welcome to-day to Columbia University in the name of every scholar that we have. (Applause.)

President Morgan from the chair requested that Prof. R. H. Thurston, first President of the Society, should return to Mr. Low its expression of thanks and recognition, which he did most happily in a brief speech from the floor, as follows:

Dr. Thurston.—Mr. President—That expression, sir, of our thanks for this kindly welcome is very soon made, but because it is a brief one it is none the less hearty and cordial. We are delighted to come to you, sir, and to see what you are doing here, not only in promoting mechanical engineering, but in promoting all arts, and all sciences, and all literatures; and as we wander about these grounds and through these buildings we anticipate exceptional pleasure in seeing in New York City a grand development of this kind, a University which is universal in its sympathy, and a University in the sense that it does represent all of the sciences as well as all of the arts, and all the literatures as well as all the sciences. And, sir, we congratulate you most heartily on the noble work that you have done in leading your colleagues, of trustees and of faculty, in the performance of this most magnificent work, and the prime pleasure of our session at this time is thus found at the meeting we are holding to-day at Columbia College. (Applause.)

The discussion of papers was then resumed up to one o'clock, when the entire visiting party was escorted to the Trustees' Room of the splendid Library Building, at which time they were introduced individually to the President of the University, and were given the opportunity to examine the notable features of the room and of the building. The party then adjourned to the ground

floor of the Engineering Building, where a luncheon was served, and afterwards the visit to other parts of the University was arranged for in detail. Parties of students were assigned as guides. Something over 600 persons were present at this meeting. The papers of the Columbia University session were as follows:

By Mr. Max H. Wickhorst, entitled "Mechanical Integrator Used in Connection with a Spring Dynamometer"; by Carleton A. Read, entitled "Apparatus for Dynamically Testing Steam-engine Indicators"; by F. Meriam Wheeler, entitled "Comparative Value of Different Arrangements of Suction Air Chambers on Pumps," and by Mr. W. H. Bristol, entitled "A New Recording Air Pyrometer."

The discussion was participated in by Messrs. A. F. Nagle, S. A. Reeve, Soule, W. O. Webber, Jacobus, Rice, Cary, Dean, Kent, Henning, Woolson, Trump, McBride, Thurston, Edw. P. Bates, and R. P. Bolton.

Fifth Session. Friday Morning, December 7th.

The closing session of the convention was convened at No. 12 West Thirty-first Street, at ten-thirty o'clock by President Morgan. Prof. W. F. Goss's paper recording "Tests of the Boiler of the Purdue Locomotive" had been postponed from the Thursday morning session, and was taken up first. It received discussion from Messrs. Rockwood, Kent, Soule, C. V. Kerr, W. O. Webber, and A. A. Cary.

The other papers of the session were then taken up in order, as follows:

By Mr. William B. Gregory, on "Tests of Centrifugal Pumps"; by Mr. William J. Keep, on "Hardness, or Workability of Metals"; by Charles E. Sargent, on "New Principle of Gas Engine Design"; by C. V. Kerr, on "Heat Efficiency of the Gas Engine as Modified by Point of Ignition,"; and by Prof. F. R. Jones, on "Power and Light for the Machine Shop and Foundry." The discussion on these papers was participated in by Messrs. George I. Rockwood, Kent, Soule, C. V. Kerr, Webber, Cary, A. F. Hall, Jacobus, H. S. Wood, Emerson, Nash, and Frith.

At the close of the debate on the last paper, the President called upon the Secretary to read certain resolutions of thanks for courtesies extended to the Society during the meeting. These resolutions were as follows:

The American Society of Mechanical Engineers, at its closing session, desires to put upon record its recognition of the courtesies enjoyed at the hand of Columbia University and its authorities, on the occasion of their most enjoyable visit to the University buildings on Thursday, December 6th.

They would ask that President Low, of Columbia University, in particular, will be assured of the hearty appreciation of his kindly words of welcome, and of the success of the great work which he has set himself to do in the building up of the new Columbia University at its splendid site.

They would express also to Mr. F. A. Goetze, the efficient Superintendent of Buildings and Grounds of Columbia, their thanks for the admirable arrangements in detail for the comfort and escort of the visitors at the University.

Resolved.—That the American Society of Mechanical Engineers requests

THE "LOCOMOBILE" COMPANY OF AMERICA

to accept its sincere thanks for the attention which has been shown to the Society during its Twenty-first Annual Meeting by that company, in putting at the disposal of the members and their guests the steam-carriages in which so much of pleasure was taken by those who could profit by this opportunity.

Resolved.—That the American Society of Mechanical Engineers will express to the

ENGINEERS' CLUB

their thanks for the courtesy shown to the Society in putting cards of invitation and the privilege of the Club House at the service of members of the Society during their stay in New York for the Twenty-first Annual Meeting of the Society

There being no other miscellaneous or new business, the President requested the incoming President, Mr. S. T. Wellman, to come to the platform, and in handing over his office to his successor, Mr. Morgan spoke as follows:

"In consideration of the work already done by our Society in the past, and in reviewing our rapid growth in numbers and in prosperity, it has seemed to me that we should be encouraged and that our effort should be to strive to do better work, that our papers may be not only more abundant, but more helpful, and to the end that our profession of Mechanical Engineering may be more esteemed at home and abroad. With high hopes for our Society and its prosperity, I leave the office of President in the hands of my friend Mr. Wellman, whom I now present to you as my final official act, with the assurance that he will receive from you the same courtesy that you have given to me."

A motion to adjourn being put and passed, the convention adjourned.

The one social event of the Twenty-first Annual Meeting was

the general reception on Thursday evening, December 6th, in the large assembly room at Sherry's. President C. H. Morgan and President-elect S. T. Wellman, with their ladies, acted as a Reception Committee, receiving the members as they entered the dancing-floor. The arrangements for the dancing were in the hands of a committee. Supper was served at ten o'clock and thereafter. Over 600 persons were present.

The city of Milwaukee, Wis., was generally spoken of as the probable place for a meeting in the spring of 1901.

No. 868.

SOME LANDMARKS IN THE HISTORY OF THE ROLLING MILL.

BY CHARLES H. MORGAN, WORCESTER, MASS.

PRESIDENTIAL ADDRESS, 1900.

In undertaking to discharge the pleasant and honorable obligation of making an annual address before you it is natural and reasonable that I should turn for inspiration and material to that small part of the boundless domain of mechanics in which it has been my pleasure and privilege to serve. Younger men may tell of what *may be* done; older men of what *has been* done. May I speak then of the rolling mill and what it has done; quickly trace its development; and show the mighty part it has played in the nation's growth. To show that with Watt's immortal invention harnessed ahead, and the hand of the mechanical and metallurgical engineer guiding behind, the rolling mill has been the plowshare which has opened the furrow and made possible the seedtime and harvest of the hour.

Important as I believe the rolling mill to be, I am not unmindful of the fact that this Society is not composed entirely of men interested in it. There are, I am sure, among the members young men engaged in rolling mill work, and older men engaged in other and highly important work, to whom a brief narrative of the landmarks of some part of the history of rolling would be of interest. If, then, aught I have to say may to some rolling mill friend seem well known and familiar, my only apology is that I do so in my desire to record that which may be of general interest to all. For I have often found it to be true that the axioms of my neighbor's trade were the problems of my own, the things by daily contact trite to him, of interest to me.

It is easy to magnify the importance of one's special work, and yet I am very bold in urging the claims of the rolling mill as an epoch maker. May the testimony I have to bring yield, under your impartial analysis, reasonable percentages of interest, pleasure and profit, but of self-assertion barely a trace.

In his annual address before the Society in 1892, our honored Past President, Mr. Charles H. Loring, pays a splendid tribute to the steam engine and its illustrious inventor, James Watt. In forceful, striking manner the influence of that invention upon the race is shown. May I ask of you another review of that address and thoughtful consideration as to what share of the truths there so ably told fairly belong to the contemporary and colaborer of Watt--Henry Cort, and the monument of his genius, the rolling mill.

"The great historian," says Mr. Loring, "who looks back a century hence upon the present era will point out *that the great underlying cause* of the wonderful progress made by mankind during the last 100 years *was the steam engine.* It is what no other machine ever was, the creator of physical power. The immortal inventor died without dreaming that he had placed on earth an infant Hercules whose club with an ever increasing might would batter down the institutions of preceding ages."

I indorse that tribute with this distinction only,—Watt's engine *is* the Hercules, but the rolling mill *is his club.* Disarm him, take his club away, and how little with his vast strength can he do? The steam engine may be "what no other machine ever was, the creator of physical power," but the rolling mill has ever been the *creator of the harness for using that power.*

Without travelling too far afield, a bit of the biography of Henry Cort, and his contemporary relationship to the work and time of Watt, is inseparably a part of any summary of the development of the rolling mill. Henry Cort was essentially to the rolling mill what James Watt was to the steam engine. There is a singular similarity between the two men and the interdependency between the development of the inventions they wrought.

They were contemporaneous, poor, engaged in other work until brought together face to face with two undeveloped bed rock basic inventions—a steam engine and a rolling mill. Both dropped the old work for the new, and developed inventions originally not their own, (for other engines preceded Watt's and other mills Cort's), but the great fundamental similarity lies in the fact that both were men who found two splendid inventions brought (as have so many lesser ones before and since) to that point in the life of inventions where development drags and waits a master-hand to give it impetus. Both were men quick to see

the needed thing and apply it, and at one stroke push the poor uncompleted thing over the dividing line and send it on its way a master product.

Henry Cort was born in 1740, at Lancaster, England. In 1765, at the age of twenty-five, we find him in London, engaged as a navy broker. Here, by sales of iron to the Government, he had pointedly thrust upon him knowledge of the conditions of England's iron industry. Within ten years after reaching London, so dependent for her iron supply had England become that Russia and Sweden, from whom she imported it, increased the price nearly two hundred per cent. No forge or furnace in England could make iron fit for the navy's use. Such a condition of things, striking at once at the root of England's maritime and naval supremacy, was intolerable. Then came one of those rare conjunctions of circumstances, too potent and far-reaching to be a mere creature of chance.

Three men almost simultaneously worked and linked together the product of their work—Watt, Cort, and the Edinburgh chemist, Black. No happier example of the power of scientific and mechanical unity can be found than in the coöperation of these three men, the scientist Black, and the mechanics Watt and Cort.

In his annual address in 1899, before the Iron and Steel Institute, Sir William Roberts Austen speaks of Black and Cort as two remarkable men who were looking for the dawn of the nineteenth century as we are for that of the twentieth, and whose work evidenced the fact that our progress received no check from the failure of industrial workers to assimilate the teaching of science.

Dr. Joseph Black, who was a professor of chemistry in Edinburgh University, previous to his familiarity with Cort's work, had interested himself in aiding Watt—indeed Watt was financially his debtor. A moment's digression concerning the relations of these men, as also the moral and physical aid of Watt to Cort, is, I feel, justifiable here. Black had a friend and fellow chemist, Dr. Roebuck, engaged in mining and wrestling with the old question of pumping the mines. To him Black introduced Watt as a young man who had invented a steam engine of increased power speed and economy as compared to Newcomen's. Roebuck's interest was instantly aroused, and, corresponding with Watt, eventually had him come to Kinneil House, Roebuck's home. There every assistance was given by Roebuck. Buildings were furnished in which to erect a working engine, the cylin-

ders for which Roebuck cast at the Carron works, of which he was proprietor, and from which he sent a corps of his best skilled English workmen to help Watt. Watt is described as a "sickly, fragile man and a constant sufferer from violent headaches. He was, by nature, timid, desponding, painfully anxious, easily cast down. . . . On the other hand, Dr. Roebuck was accustomed to great enterprises, a bold, undaunted man, disregardful of expense where he saw before him reasonable prospect of success. . . . The result was Dr. Roebuck eventually became a partner in the invention to the extent of two-thirds—took upon himself the debt owing by Watt to Dr. Black, and undertook to find the required money to protect the invention by a patent."

Such was the friend to whom Black introduced Watt, and such was the moral and material backing Roebuck gave that Watt, in writing to a friend, says: "I have met with many disappointments, and I must have sunk under the burden of them if I had not been supported by the friendship of Dr. Roebuck." And yet it is of such a man as Roebuck—who ruined himself financially with his tireless energy—that the best the biographer can say in a Cyclopædia of Biography published in Glasgow is, "Roebuck, John, a physician and experimental chemist, born at Sheffield in 1718, died, after ruining himself by his projects, in 1794."

Such was the advent of Watt and his engine, and the part Black played in it. The new invention had about gained a fair footing when Henry Cort began his work. Cort—the man with whom Sir William Roberts Austen says "Black was soon to become familiar"—the man of whom Watt, in writing to Dr. Black, says: "Mr. Cort has been most illiberally treated by the trade; *I shall be glad to be able to be of any use to him.*"

Of how great a use he really was, no human mind can ever know. Omniscience alone can measure the help to the struggling Cort of such kindly, sympathetic appreciation as that of Watt. Watt, of all men, who, when struggling in the initial throes of his own work, had the friendly interest of Black and the broad shoulders of Roebuck to sustain him. There was singular fitness now that it should be this same Black and Watt, and the assistance of their discoveries and inventions, that should be the key for Cort to open his own. With the chemical researches of Black and the steam engine of Watt ready and available, Cort went at the very root of the method of puddling iron and the machinery for rolling it.

Possessed of a small competency saved from his brokerage business (some £20,000), Cort dedicated the whole of it to perfecting the processes and machinery for manufacturing iron. He leased a site and built a mill at Fontley, near the government docks in Portsmouth Harbor, and here, between 1777 and 1783, prosecuted the work which culminated in his patents for improvements in the process of the manufacture of iron and the manipulation of it by the use of the grooved rolls. There in those two obscure patents, Nos. 1,351 and 1,420 of 1783 and 1784, respectively, are bound up the first real beginnings of the art of rolling iron and steel; beginnings that were no mere fortuitous accidental discoveries, but discoveries made by a man who saw what was needed and went for it with incisive directness. With his skilled method of "puddling," an end came forever to the manufacture of iron "no longer fit for the navy's use." With his first use of the grooved rolls, the limitations of the old slow hammer were burst, and an evolution started, the end of which is not yet. It is impossible to overstate its value. At the very start it brought emancipation from dependence upon Russia and Sweden, aside from the financial freedom it secured. Nor from the standpoint of pounds, shillings and pence, can the mind fully grasp the significance of Cort's invention. As early as 1786, only two years after the date of the patents, Lord Sheffield said: "If Mr. Cort's very ingenious and meritorious improvements in the art of making and working iron, the steam engine of Boulton and Watt, and Lord Dundonald's discovery of making coke should all succeed, it is not asserting too much to say that the result will be more advantageous to Great Britain than the possession of the thirteen colonies [of America]."

An invention which in two years was able to throw a searchlight into the future and reveal possibilities calling forth such an utterance must be stamped as something more than ordinary. In 1865, about eighty-two years after Cort's invention, William Fairbairn said: "Henry Cort's inventions have conferred an amount of wealth on Great Britain equal almost to six hundred million sterling, and have given employment to six hundred thousand men." Surely such declarations justify the assertion of kinship between the development of the rolling mill and that of the nation.

The temptation is strong to trace in detail the tragic career of poor Cort, but it is not within the limits or purpose of this paper to do so. I may, however, briefly say that, reaching the limits of

his twenty thousand pounds, he entered into that fatal partnership with the Jellicoes, by which the capital of the father, Adam Jellicoe (then Deputy Paymaster in the Navy), was put into the business. Cort's patents were assigned to Jellicoe as collateral, and later were confiscated by the government upon the discovery of Adam Jellicoe's defalcation, and that the capital advanced by him had been taken from government funds.

His biographer says "He may be said to have been . . . the author of our modern iron aristocracy. These men of gigantic fortunes have owed much—we might almost say everything—to the ruined projector of 'the little mill at Fontley.' Their wealth has enriched many families of the older aristocracy and been the foundation of several modern peerages, yet Henry Cort, the rock from which they were hewn, is already all but forgotten. . . . He has been the very Tubal Cain of England . . . and while the great iron masters, by freely availing themselves of his inventions, have been adding estate to estate, the only estate secured by Henry Cort was the little domain of 6 feet by 2 in which he lies interred in Hampstead Churchyard."

I may say that it was my pleasure during the recent trip of the Society abroad to have had made a photograph of "the little domain of 6 feet by 2 . . . in Hampstead Churchyard." The markings on the headstone were much obscured, but by a little effort they were cleared and a satisfactory photograph obtained.

I have felt it to be of interest, and worthy the emphasis given, to outline thus the life of a man with whose work the real art of rolling began. Before Cort's time, strictly speaking, there was no such thing as the manufacture of bar iron by rolling, although it is but just to say that Christopher Polhem of Sweden, who had done valuable work with plain rolls, anticipated in his writings the possibilities of grooved rolling, stating, in substance, that financial and other limitations restrained him and that it must be left for others to work out. Cort was the man who worked it out. The art as he found it was simply the crude refinement of the pig iron in small quantities into the wrought iron mass—its manufacture into bars, alone by hammering—with a finishing pass between plain rolls for uniform thickness before cutting in the ordinary slitting mill.

Cort reorganized the whole scheme—metallurgically and mechanically. Laying the foundation of modern puddling—minimiz-

ing the use of the hammer and practically discarding its use for finished work, he took his refined mass at once to his grooved puddling rolls and thence on to the finishing; using, as he says in his patent, "a groove of the required diameter when the iron is designed for bars, half flats, or thimble iron, either plain for squares and flats, or concave for bolts and the like."

Then, for the first time, the infant industry for rolling stood alone, all before had been but gathered strength for taking the first step. To trace minutely its growth would fill volumes. As an index of immediate effects of Cort's improvements, take, for example, the work of Richard Crawshay, one of the first iron masters to appreciate and adopt them. In 1787 he was struggling away at Cyfartha, making, under the hammer, barely 10 tons of bar iron per week, and that none too good; yet in 1812 (twenty-five years later), in a letter read before the House of Commons, describing his process, he states: "I took it from a Mr. Cort, who had a little mill at Fontley, in Hampshire, ... by which I am now making more than 10,000 tons of bar iron per annum" (equivalent to 200 tons per week). From thence on, these outputs have mounted up until, in the United States alone, there were rolled in the year 1890 (excluding all flat roll products) about 5,000,000 tons of iron and steel—equivalent to 100,000 tons per week, and, in 1899, over 8,000,000 tons—equivalent to 167,000 tons per week, every pound of which passed through grooved rolls like those first used in the "little mill at Fontley."

The mill used by Cort was, of course, of the ordinary 2-high type. Modification after modification succeeded Cort's 2-high mill, calling forth all sorts of types, kinds, and classes, among them the familiar reversing and 3-high mills, all evolved by the demands of advancing civilization in ever varying and countless combinations, for something bigger and better, longer and stronger.

The Continuous Mill.

It has been the privilege of the writer to have been allowed to add his contribution to this development of the rolling mill; to have shared in aiding the development of that type of mill known as continuous mill, and the large family of auxiliaries that have grown up about it. Like all inventions, it had its day of small beginnings. There are footprints of tentative efforts made in France to use it. The first recorded patent and first actual use

seems to have been that of an American, J. E. Serrell, in 1842–43. Its use was, however, restricted by him to the rolling of lead pipe and copper, and with his efforts his use of the mill ceased. His countryman, Henry B. Comer, in 1859, secured a patent for a continuous mill, but never constructed one of this type.

Like Cort's invention, other men thus had their hand on the tiller before the captain grasped it. By every consideration, the credit for first impressing the continuous mill into the service of rolling iron and steel, for successfully combining its essential elements, and for gaining it the wide application it now enjoys, is due to Mr. George Bedson of Manchester, England. *He first made the mill go.*

This mill, as its name implies, works continuously upon the metal. The rolls are placed closely in tandem and the metal led by means of guides directly from pass to pass, without the intervention of any human labor. There are no interruptions, no catching or looping, but a continuous onward transit of the metal from the bite of the roughing rolls to the discharge of the finishing. Each pair of rolls, by carefully arranged gearing, being speeded according to the reduction of each successive pass, to take up the corresponding elongation. Phenomena peculiar to this mill had to be combated, but the door was at once opened for vastly increased lengths, weights, and speeds. Europe, at that time, was rolling easily 50-pound billets by the Belgian or Looping System; the United States but 15 pounds on ordinary 2 and 3-high mills. The Bedson Mill at once handled from 70 to 80 pounds (which was rapidly increased until to-day 300-pound billets are commonly rolled).

The Hon. Abram S. Hewitt, statesman, iron master, and wire manufacturer, speaking of this in his report as United States Commissioner to the Universal Exposition, at Paris, in 1867, says: "Generally there may be said to exist a prevailing willingness and practice in the European works to handle iron in larger masses . . . than we do in the United States. . . . wire rods are frequently to be found in the departments ranging from 30 to 50 pounds in weight, rolled in trains . . . no greater in speed than we employ in the United States for 15-pound billets. . . . but the most remarkable specimen of rolling was in the English department exhibited by Richard Johnson and Nephew, of Manchester, in the shape a coil of No. 3 wire rod, weighing 281 pounds, in length 530 yards, rolled from a

single billet. . . . This wonderful specimen of wire rod . . . was rolled in a machine invented by George Bedson."

The first of these continuous mills erected in the United States was at the works of the Washburn & Moen Manufacturing Company, Worcester, Mass. Mr. Ichabod Washburn, the founder of that company, recognizing the great possibilities of this mill, negotiated with Mr. Bedson for one of them, and assumed, personally, the entire financial risk of the venture.

In the spring of 1869 this mill, designed and constructed by Mr. Bedson, was erected and put in operation, under the supervision of the writer, at the Washburn & Moen Company's works, of which he was then general superintendent. This mill is shown in Fig. 1, and consisted of 16 stands of rolls placed in tandem, and rolled $1\frac{1}{8}$-inch billets, weighing from 70 to 80 pounds. For the general reader, I may say that it is evident that continuous rolling of a billet in a plane always at the same angle to its axis, would produce flattening of the mass only. To obtain elongation, compression in planes varying in angle with that of the axis is necessary, similar to the rotation of the metal by the blacksmith upon the horn of the anvil between each successive blow. In Mr. Bedson's mill this was accomplished by placing each pair of rolls (after the manner of the universal mill) at an angle of 90 degrees to its predecessor. This secured the desired end perfectly, but entailed vast annoyance in the care and management of the mill. By it was necessitated the use of one system of gearing above the floor line and another in a pit below it. Accessibility to these, as also to the rolls themselves, in changing and adjusting, was seriously impeded. In the next continuous mill, Fig. 2, which was designed by the writer in 1878, and used by him at the Washburn & Moen Company's works, all rolls were placed in a horizontal plane, all the gearing in a single plane, and the very essential requisite of varying the plane of compression secured by the use of *twist* guides, whereby the metal was turned 90 degrees in travelling between each successive pass; a device universally adopted in these mills.

It would be quite impossible to trace each minute development. As in all new things, surprises constantly had to be met and overcome. Nicety of adjustment became inseparably a feature of the system. Exactitude in the corresponding speed and passes of the rolls was difficult. Without it one of two things was inevitable—delivery to a pass faster than its capacity to receive it,

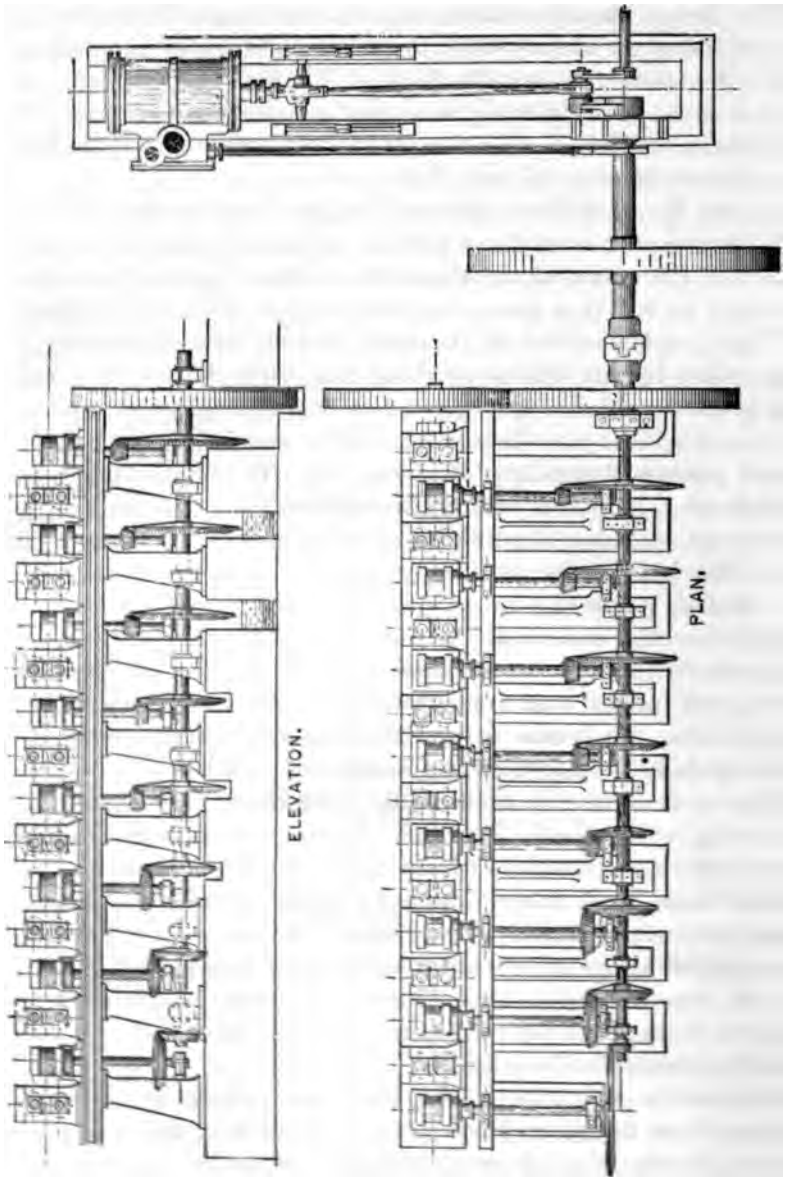

FIG. 1.—BEDSON CONTINUOUS ROD MILL, 1869.

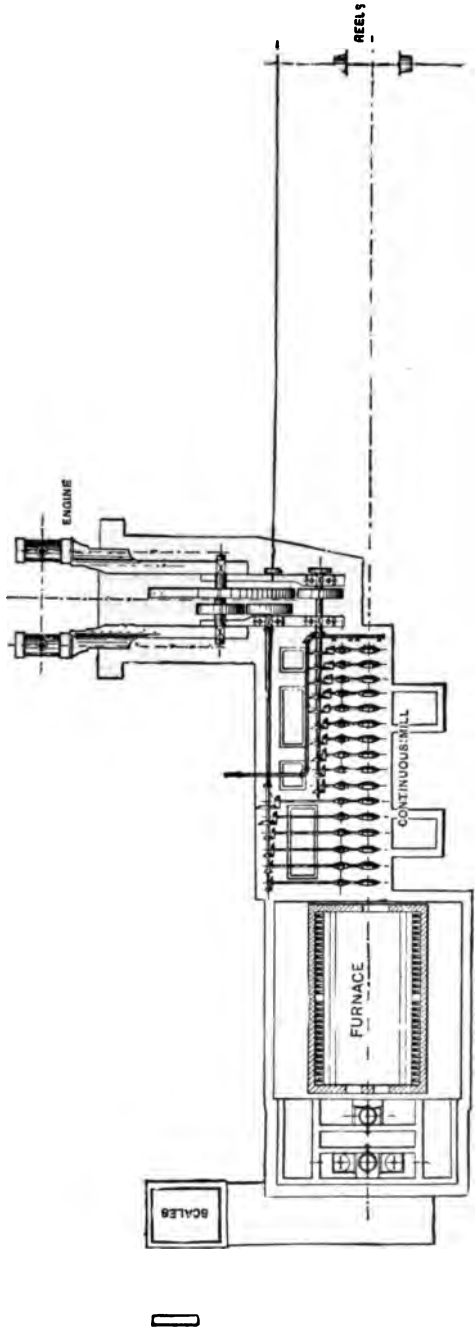

FIG. 2.—MORGAN CONTINUOUS ROD MILL, 1878.

producing lateral looping; or slower than its capacity to receive it, producing stretching. Of the two alternatives, the latter was preferable, for the relief by looping was interfered with by the guides—it was cumulative in effect, and attended with serious menace to the safety of the mill and its operatives. Stretching, however, threw a demand upon the heated metal greater than many grades of good iron could withstand, by reason of their low tensile strengths and lack of homogeneity. For this reason the use of the continuous mill, as originally installed, was greatly lessened in rolling common grades of iron; so much so, that the next mill built by the Washburn & Moen Company, in 1877, was a 3-high mill adapted to the Belgian system. The improvements in Bessemer and Open Hearth steels, with their greater tensile strength and homogeneity, ultimately brought a product for rolling for which the continuous mill was well adapted.

Belgian or Looping System.

With increase in weight and decrease in the section of the finished product there arose the practice of *continuous* or *simultaneous* rolling of the metal in 3-high mills by serpentine looping on each side of the mill. This was distinguished from the "back and forth" rolling, in which the metal was discharged free from the rolls at each pass. This type of mill was used by Europe before the United States adopted it—presumably first in Belgium, the name "Belgian" having come to be understood as meaning a looping mill. It was the use of these mills which for some time enabled the European manufacturers to roll the 30 and 50-pound billets referred to by Mr. Hewitt while we were rolling but 15 and 20 pounds on the "back and forth" 3-high mills. It was a mill of this Belgian type which was first designed and erected by the writer to follow the original Bedson continuous mill, as already mentioned. A plan of this mill is shown in Fig. 3. It is believed that this was the first "Belgian" mill erected in the United States, although other mills were erected at or about that time by others. At all events it was one of the very first of these mills thoroughly carried out and put in for permanent and effective service in this country. The roughing was done on a 2-high mill capable of handling 4-inch billets, reducing to $1\frac{1}{8}$ inches. From this size it went to the looping or Belgian mill, and rolled to the ordinary wire rod. This system is now used quite largely in this country for rolling wire rods.

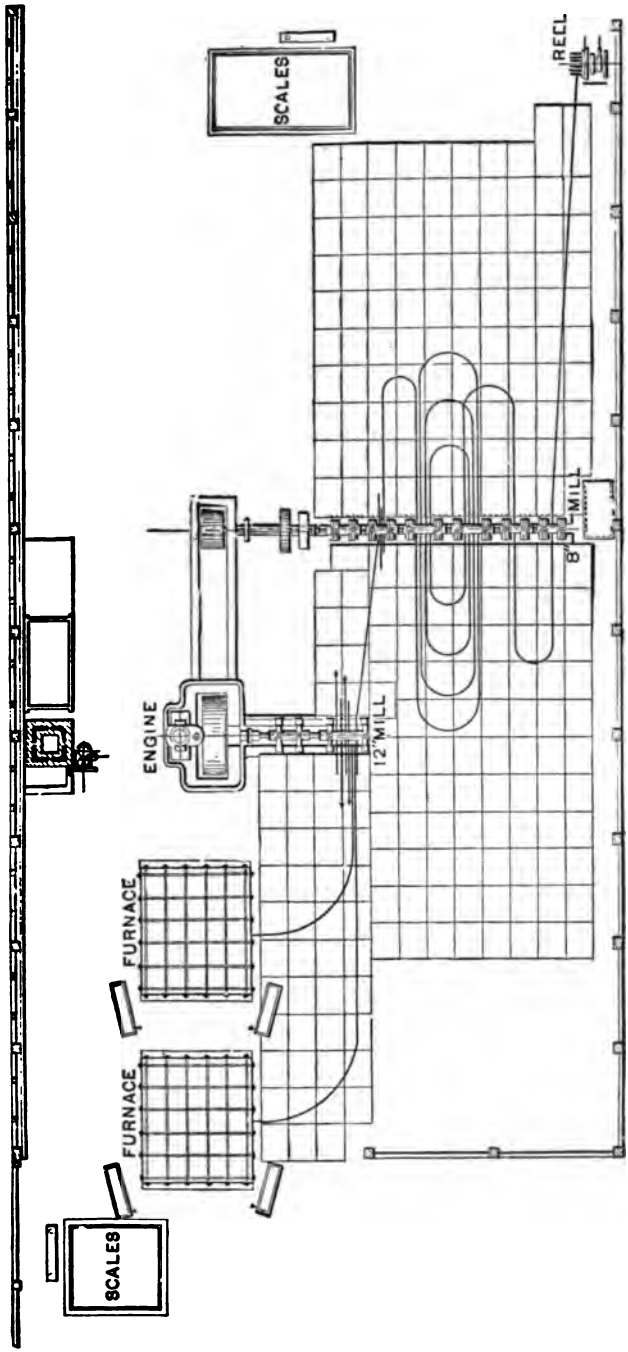

FIG. 3.—BELGIAN ROD MILL, 1877.

Combination (Continuous-Belgian) Mills.

The combination or joint continuous-Belgian mill (Fig. 4) was an effort on the part of the writer to secure a consolidation of the merits of both systems. A mill of this type was put in operation by the writer in 1881 at the works of the Washburn & Moen Company. It roughed billets of about 100 pounds in weight from 1 3-16 inches to $\frac{5}{8}$ inches on the continuous mill, and finished from $\frac{5}{8}$ inches on the Belgian mill to the ordinary wire rod. This was the first mill of this type built in this country, or in any country. One of the chief merits of this system is that it rolls common iron equally as well as does the looping or Belgian system, and that, too, with less labor. It has since been adopted by the advocates of the Belgian system as a compromise recognition of the claims and merits of the continuous plan.

With increase in size and weight of billets, as has been said, the accessories of the mill began to grow, although the need for something new at the delivery end of the mill soon followed. The leap from billets and coils of 15 and 20 pounds to those of 70 and 80 forced a "policy of expansion." The mill itself had undeveloped capacity—the limitation lay in the heating and reeling, two collateral functions of the mill which have had a rapid and interesting growth.

Heating.

Heating in Cort's time had probably been done in some form of "direct-fired" furnace (similar to an ordinary puddling furnace), the metal charged and discharged from the same door. These furnaces were in every way extravagant, consuming large quantities of fuel, most of the heat being lost up the chimney; a heavy percentage of the metal was lost by oxidation, and, in later years, the higher carbon steels were seriously injured by the abruptness with which they were exposed to the full intensity of the heat.

In course of time there developed a class of furnaces known as "gas-fired" (as distinguished from direct-fired). Heating was obtained by the combustion of "producer gas" (a gas obtained by the distillation of coal).

Fuel economy, intensity of heat, and facility of regulation were important advantages of this method of heating. The chief advantage, however, lay in the ease with which an "oxidizing" or a

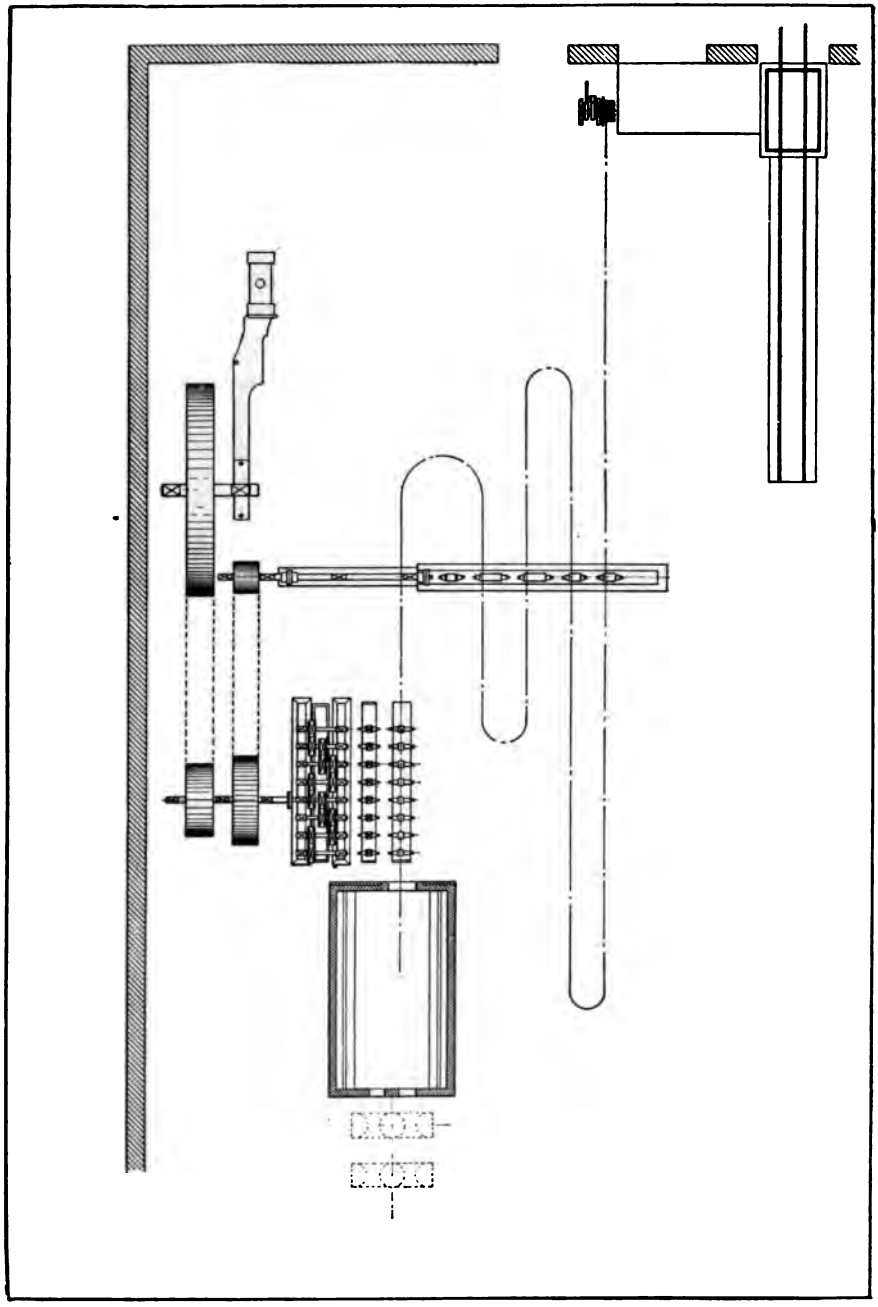

FIG. 4.—COMBINATION (CONTINUOUS-BELGIAN) MILL, 1881.

"reducing" flame could be secured, for by it the oxidizing, or "scale-waste" of direct-firing, was very materially reduced.

Modifications of these furnaces followed, until two general types came into accepted use—the "Ekman continuous" and the "Siemens regenerative." Both were gas-fired, and therefore had all the general advantages of that method of firing; but both aimed *specifically* at greater efficiency by utilizing the waste heat escaping with the products of combustion. They aimed at the same thing, but effected it quite differently. The Siemens regenerative (the last in point of time—1856—but the first to be generally accepted) secured "regeneration" by causing the waste heat on its way to the stack to pass through the interstices and to be absorbed by fire-brick "checker-work" placed in suitable chambers. Alternation in heating the checker-work was had between two pair of these chambers, through which the inflowing gas and air, respectively, passed on their way to the furnace, absorbing the heat of the fire-brick checker-work, uniting at a high temperature with a high resultant flame. These furnaces stood in great favor, and deservedly so, for steel making, but they had disadvantages for reheating cold metal. Charged and discharged, as they were, from the same door, there was often confusion in the order and system of receipt and delivery, the last billet in often being the first one out (something like the experience our steel friends have when order and sequence at the soaking-pits is disturbed and uncertainty exists as to which ingot should come next). But above all was the disadvantage of exposing the cold steel to the full intensity of the heat. Efforts have been made to overcome this by the use of two furnaces of high and low temperature, respectively; but the neatest, simplest, and most effective design for securing this end has been that of Gustave Ekman, of Sweden (1843), nor was the element of absorption of waste heat neglected. The very same design is made to do double duty and secure both ends, and therein lies the great beauty and adaptability of these furnaces. For regeneration, or recoupment of the heat, Siemens depended upon the absorptive action of the fire-brick, from whence it was returned to the furnace. Ekman at once made the *oncoming metal itself* absorb the escaping heat, an arrangement in itself manifestly simple and effective, but vastly so in the light of the fact of the greater absorptive capacity of the metal over the fire-brick.

Nor does Ekman stop here. After running the gauntlet of the

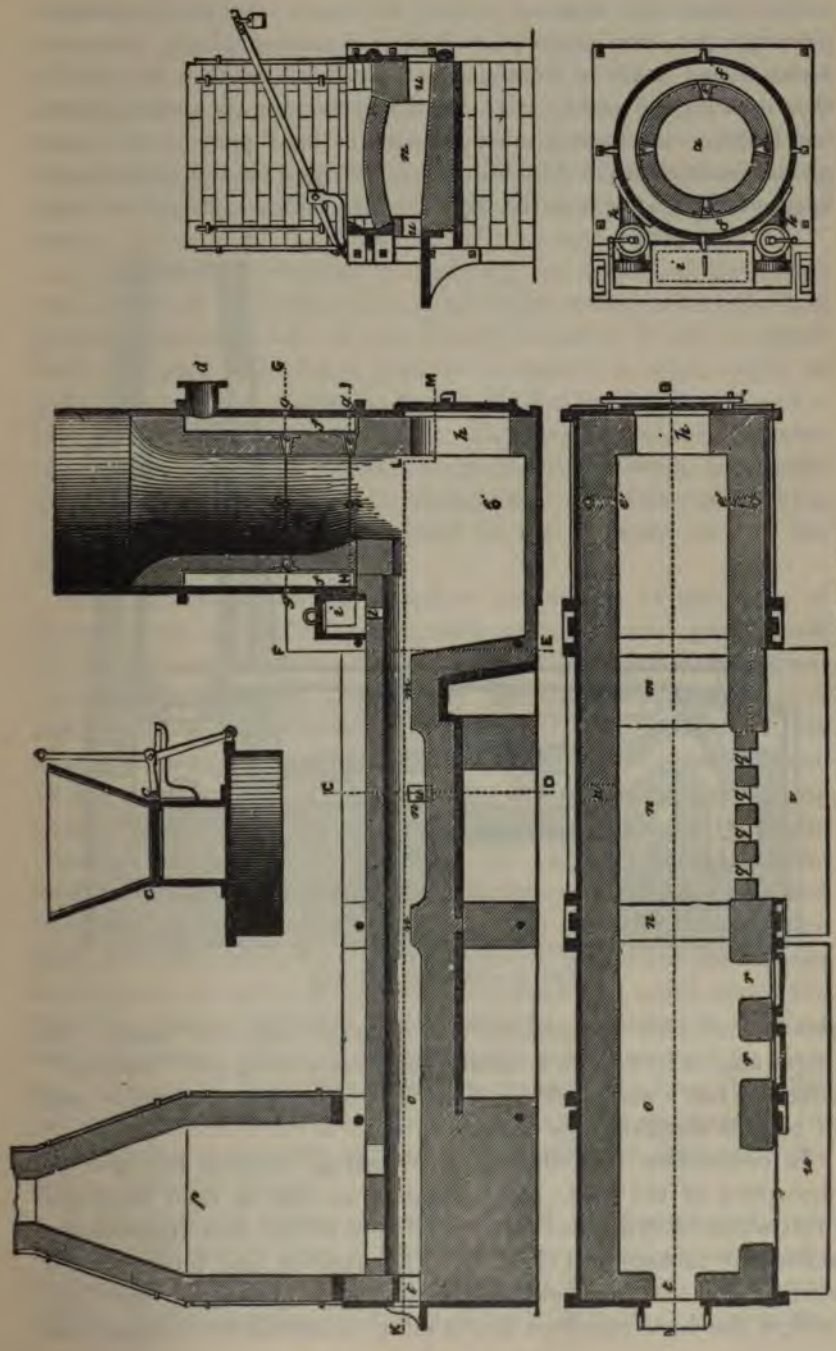

FIG. 5.—EKMAN FURNACE.

cooler billets, the heat is met by a "stove," or similar device, placed in the stack, by which further retention of the heat was secured and used in heating the air-blast. Such a furnace is shown in Figs. 5 and 6. *Length*, it will be seen, is a distinguishing feature—it might almost be said to be a part of the stack placed horizontally. The billets are charged at the cooler, and, by gradations approach the higher heat. With high-carbon steel

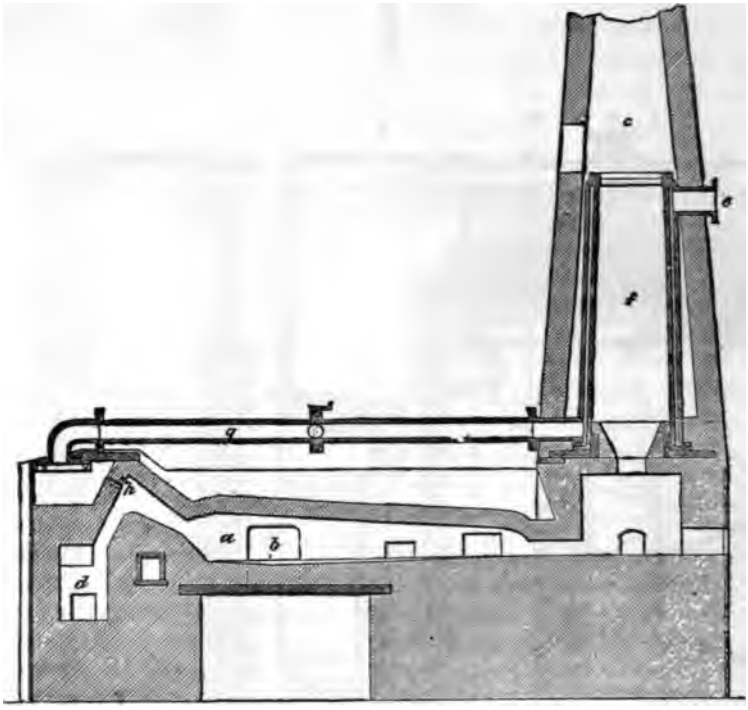

FIG. 6.—EKMAN FURNACE.

this is absolutely imperative, and desirable with any metal. It might almost be said to be a simultaneous heating and "soaking" effect, to use a steel-maker's term—the billet delivered ready and in perfect condition for rolling.

In connection with this quasi "soaking" feature lies that of absorption of the waste heat. Ekman, as will be seen from the illustration shown, places a second low bridge wall transversely across the furnace bed (Fig. 5). This retards and tends toward confinement of the heat at the hot end. Escaping over the bridge, the heat envelops and is either absorbed by the long line

of oncoming billets, or, passing them, is arrested by the stove in the stack. Gradation in heating and passage of the bridge was effected by withdrawal and insertion of the billets at the side doors shown. In a modification of this furnace, called the "roll oven," seen by the writer at Hoerde, Germany, about 1880, this was effected by giving the billets an octagonal section, and *rolling* them the entire length of the furnace by barring through lateral doors. In all these furnaces, the bottoms were of sand.

A decided improvement in effecting the transit of the metal was that made by William D. Allen about twenty years ago, then general superintendent of the Henry Bessemer Works at Sheffield, England. Mr. Allen placed the metal on skids made of wrought-iron pipe protected from burning by maintenance of a water circulation through them. This was a decided improvement, dispensing with barring, lessening the friction, and made possible the movement of the entire mass of billets onward by a hydraulic pusher, which he placed at the charging end of the furnace.

From this point on, the manifest advantages of this type of furnace have claimed attention, and caused a rapid growth and development of important modifications. Two of these, designed by the writer, are here shown, the "gravity discharge" (Figs. 7 and 8), and the "suspended roof" furnaces (Figs. 9 and 10). Both, as will be seen, have all the essentials of the Ekman-Allen furnace. In the former (gravity discharge) the billets are pushed to the hottest zone of the furnace, from which they descend by an incline (set at an angle greater than the angle of friction) to the feed rolls and thence on to the mill, thus avoiding the slow and laborious operation of barring the metal out employed in the Allen and other furnaces. The inclination upward of the furnace bed is given to secure the gravity discharges at a point above the floor line instead of below it, as would be necessary if the bed was horizontal. Great furnace capacity can be secured by placing a series of these furnaces side by side, fed from the billet pile by a common conveyor in the rear, and all discharging by gravity upon a common system of feed rolls for delivery to the mill as shown in Fig. 8.

In the feed roll system, shown in Fig. 8, the delivery rolls are conical, with an extension of lesser diameter and consequent lesser surface speed. The cold billets retained by lateral guides are conveyed on the inclined surfaces of the rolls until at or near the

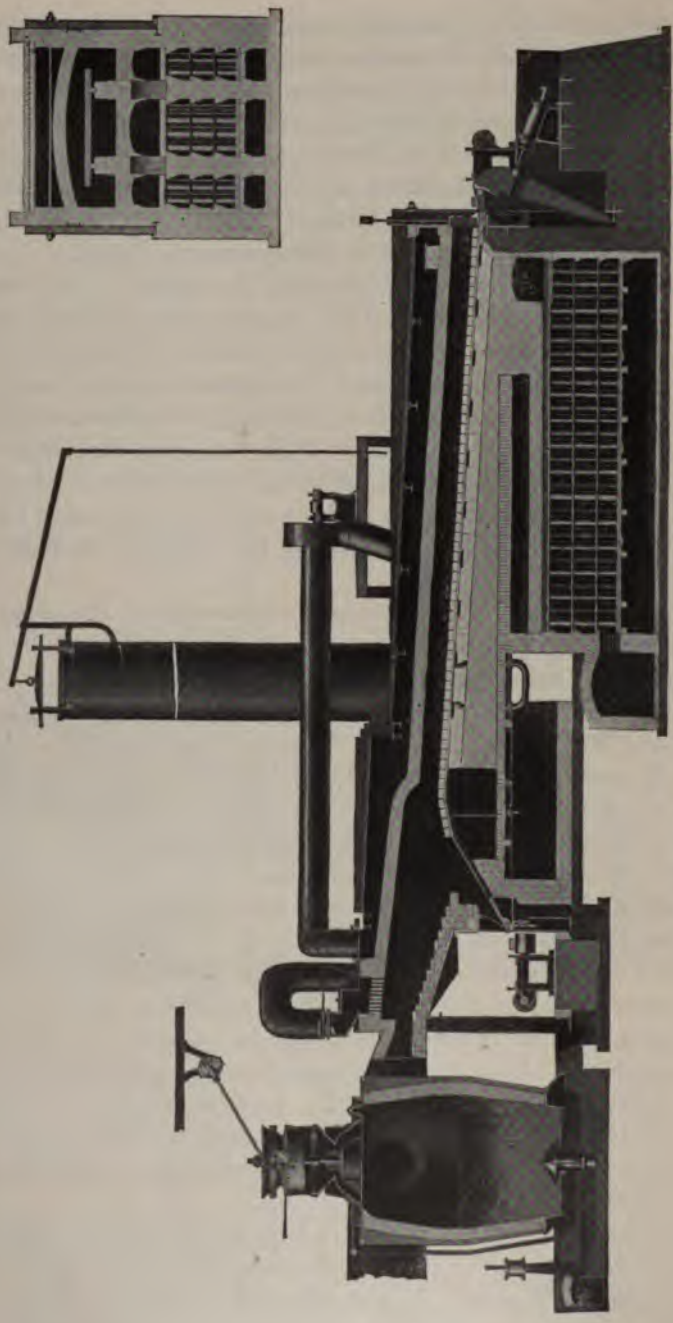

FIG. 7.—MORGAN GRAVITY DISCHARGE FURNACE.

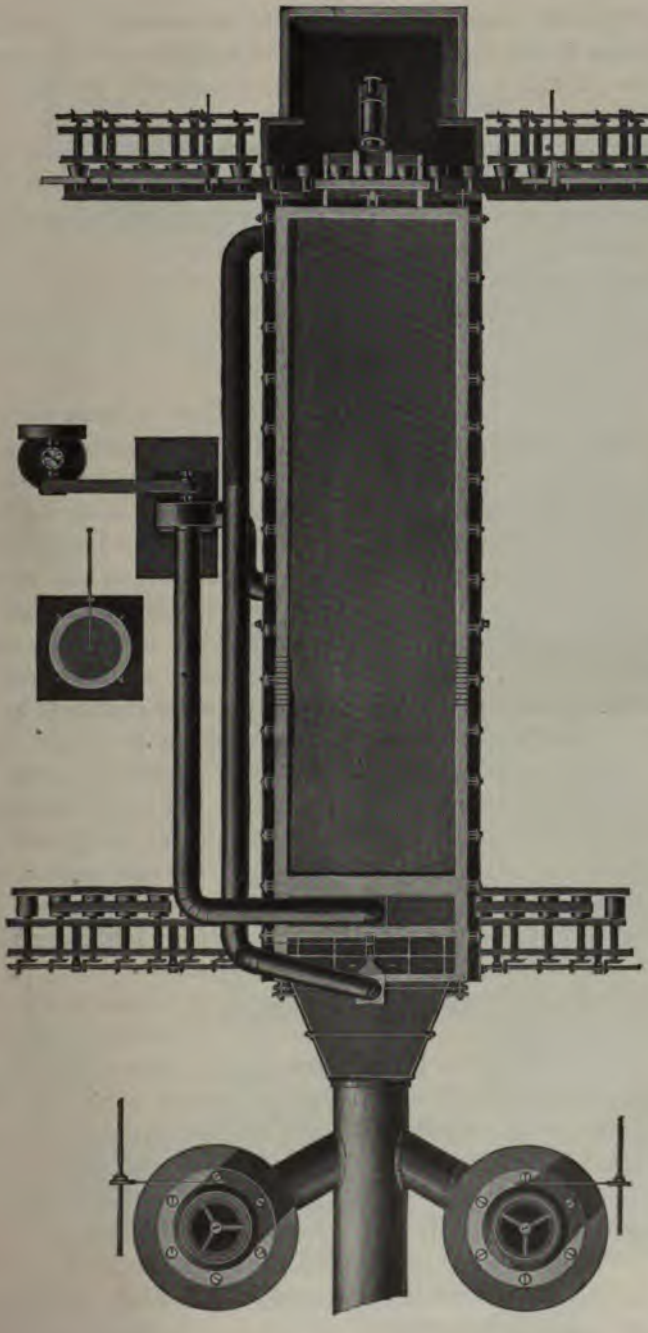

FIG. 8.—MORGAN GRAVITY DISCHARGE FURNACE (PLAN).

furnace, where the guides are "switched" or withdrawn, and the billets allowed to fall and travel at the slower speed upon the small ends of the roll below, being brought to a standstill by any suitable stop.

The development of the suspended roof furnace was an outgrowth of the necessity for using billets small in section but long in length. Experience has shown that in rolling finished products of small section, complete uniformity was obtained with less loss from oxidation by the use of billets correspondingly small in section than by using shorter lengths of larger section. The usual length of billet for the "suspended roof furnace" is 30 feet, the length suited to the ordinary freight car.

The necessity of *lateral* presentment of billets to flame for uniform heating I have already shown. To effect this, therefore, with a 30-foot billet called for corresponding increase in furnace *width : length* had already reached 30 to 50 feet for securing continuous and gradual heating. To support a roof suitably over such dimensions necessitated something more than the means ordinarily used. The writer devised a roof consisting of a series of arches supported by skewbacks, suspended from transverse girders resting upon the furnace walls; suspension being had by attachment to water pipes running through the skewbacks (Fig. 9). This roof has had a thorough practical test for five years past, and has worked quite satisfactorily. The essential points of Ekman and Allen are easily recognized in it, except that heat localization, which Ekman secured by his second bridge wall, is here obtained by the reverberatory effect of the roof arches, and the water-pipe skids of Allen are confined to the cool end of the furnace only, by looping back, though in some instances they have been deflected downward through the bed.

The method of charging these furnaces is shown in Fig. 10, the billets being run into the furnace *in the direction of their length* (not broadside, as in former Ekman-Allen furnaces). They are presented gradually broadside to the hottest zone, and discharged again longitudinally; a power pusher starting them forward to the bite of the rolls, which are placed close to the furnace door. Special reference is due to the ease with which repairs to this roof can be made without material interference with its structure. Parts of the arches or skewbacks can, with perfect ease, be taken out and replaced without affecting contiguous parts, these roofs having enough spring and flexibility to adapt

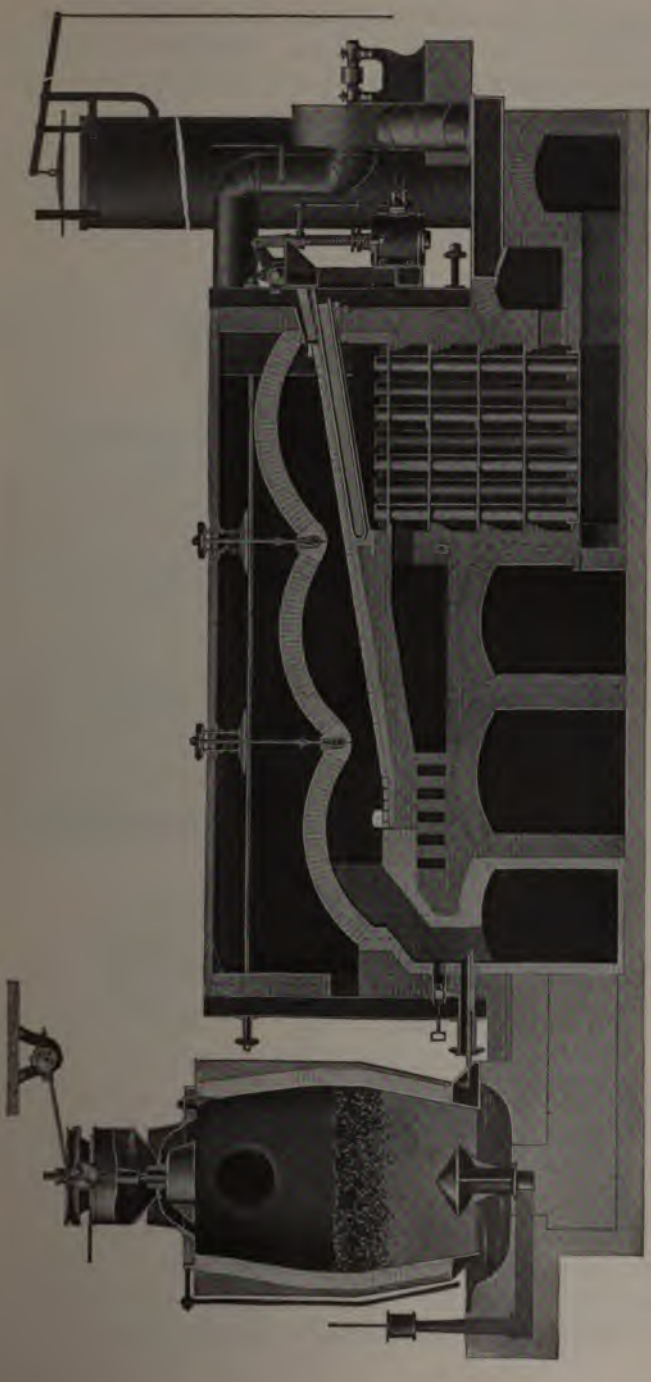

FIG. 9.—MORGAN SUSPENDED ROOF FURNACE (PLAN).

themselves to the stress of heating and cooling, or to any ordinary strain. They are, in addition to the purposes above outlined, well adapted for heating such long pieces as old rails for re-rolling.

Reels.

Increase in weight from the 15 and 20-pound billets rolled in the old mills to the 70 and 80-pound billets rolled in the original

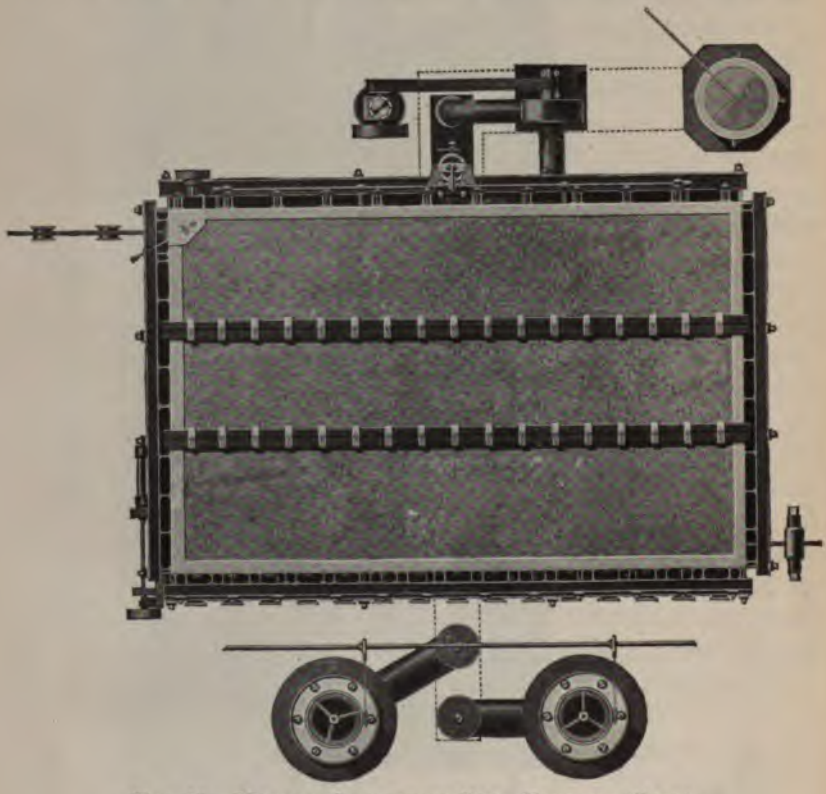

Fig. 10.—Morgan Suspended Roof Furnace (Plan).

Bedson continuous mill forced improvements in reeling. The old hand reels were tried, but the labor was too exhausting, and even when used they cramped and hampered the full efficiency of the continuous mill.

A power traction reel, as shown in Fig. 11, was designed and used by the writer in 1869. It worked well, but its capacity was, after a time, exceeded. With the ever-increasing length and weight of coils, new factors had to be reckoned with. Originally,

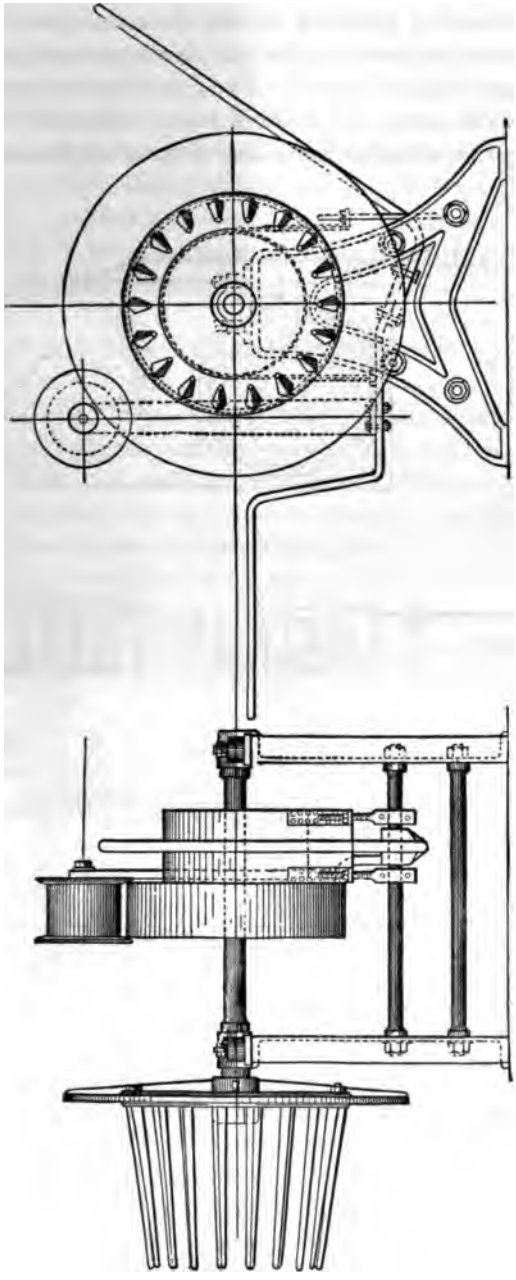

FIG. 11.—MORGAN TRACTION ROD REEL.

wire rods were discharged and spread over an expanse of iron flooring—the free end inserted by an attendant into the reel, which was speeded to overtake the roll discharge and gather the accumulated loops from the floor. The great floor space required for the larger coils—the high reeling speed required for "take-up"—the danger to attendants and loss from entanglement—these

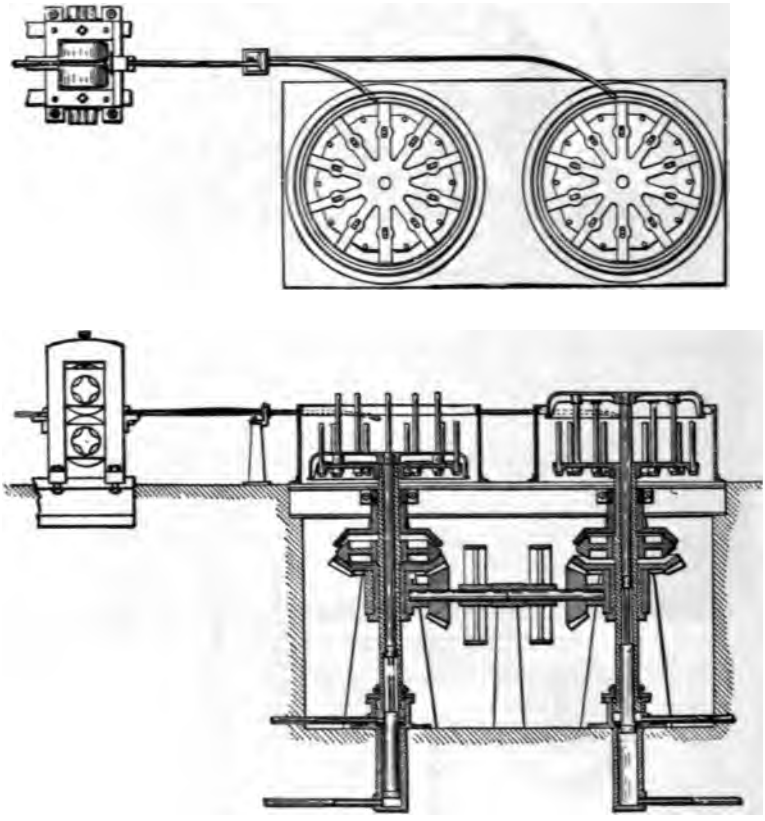

FIG. 12.—MORGAN AUTOMATIC POURING ROD REEL.

and other difficulties gradually forced this reel aside. The writer designed and used at the works of the Washburn & Moen Manufacturing Company a reel such as shown in Fig. 12.

The automatic pouring reel, Fig. 12, has a hollow vertical shaft, on the upper end of which was fastened a disk. Near the outer ed › of the disk a row of upright pins were attached thereto, arer the centre of the shaft, and about six inches from the per-

iphery was a second row of upright pins. This reel was provided with another disk or platform attached to a shaft, which was inserted and projected through the shaft of the reel; at the lower end thereof was a hydraulic cylinder and piston for moving the last-named lifting-platform, and for the removal of the rods after reeling. Between the two rows of pins the wire rod was coiled as it issued from the finishing rolls of the mill, and conducted through a pipe which guided it to the reel. The operation was somewhat like pouring a small stream of water into a revolving tub. All the difficulties of floor looping were eliminated by placing the reel close to the finishing rolls.

This reel has been almost exclusively used by the Washburn & Moen Manufacturing Company in connection with its mills. It is properly a landmark in the evolution of automatic power reels. Like Cort's invention, however, the child was so attractive that rival claims of parentage contested. With varying successes, they were carried through courts of minor jurisdiction until the Supreme Court of the United States, with the wisdom and equity of a Solomon, refused to divide the child, and irrevocably awarded it to the writer as his own.

Another form of reel designed by the writer and one of his associates was the "laying" or "whirling pipe" reel. As the name would indicate, the wire rod was *laid* in a receptacle by means of a rotating pipe. These reels were not used by the Washburn & Moen Manufacturing Company, but received a most flattering compliment and endorsement from the wire-rod fraternity by the very general way in which they were appropriated and used without so much as "by your leave, sir." A singular incident to this method of reeling was the gradual spiral twist given to the rod—thought, at first, objectionable. It appeared in time, however, that imperfections in the rod by "under or over filling" in the rolls were thus distributed spirally upon the rod, and not straight and longitudinally. The inventors builded better than they knew, for by this quality the excessive wear upon the die in cold drawing was distributed around its inner surface, and not confined to wearing and cutting at one point.

Accessories.

I have already noted the influence upon development of the demand for greater things. The design of the mill and the accessories about it soon came to have the imprint of the specific

use intended. Little by little the limitations of human endurance were reached. With each new device there still lingered enough of direct human labor to fatigue and hinder. All these had to stand aside, until the function of labor has become largely *supervisory* and *directory*, rather than *executory*.

Originally, the *furnace* and the *mill*, the *heating* and the *rolling*, comprised the whole. To-day, appliances, formerly mere convenient accessories, have risen to the dignity of indispensable parts. Human nature and the native distaste for physical effort could fairly be counted upon to prompt some mechanical relief, but something more than love of ease and relief from labor inspired the growth of the modern accessories. *Necessity forced the issue;* developing the beautiful adjuncts now inseparably a part of every modern mill.

Stand before one of Mr. Carnegie's magnificent mills and watch the great glowing mass come on, over the feed rolls, from somewhere—actuated by something—enter the rolls, be lifted, turned, and carried on the feed table, operated by somebody, discharged, and sent out and away, on the automatic carriers, a finished billet, plate or beam. How many men would it take, and how long would it take them, to do the work that has been done by the "mere accessory"? How much would the mill have rolled without it?

I have already shown how the capacity of the continuous mill for rolling greater wire rod products forced an evolution in *its* accessories. Nowhere has this been greater than in the mills built for *miscellaneous* uses. In and around the Pittsburg district, continuous mills have in recent years found great favor for rolling such products as merchant steel, billets, hoop, and cotton tie, etc. Continuity of operation has been the touchstone throughout. Here again, however, length of the finished product forced recognition. A 6,000-pound ingot with the initial heat of the converter, without reheating, is easily rolled directly and continuously to 1½-inch square bar. When so rolled it involves a length of nearly 800 feet; luxury of yard room to accommodate which few mills can afford to give. Handling the straight 800-foot product was impracticable; reeling it equally so and, in fact, undesired. Stoppage of the moving metal by fixed cutters during delivery from the mill there could not be, with the attendant buckling of the oncoming mass. To meet the requirements, a shear, shown in Fig. 13 (called by the workmen the flying shear)

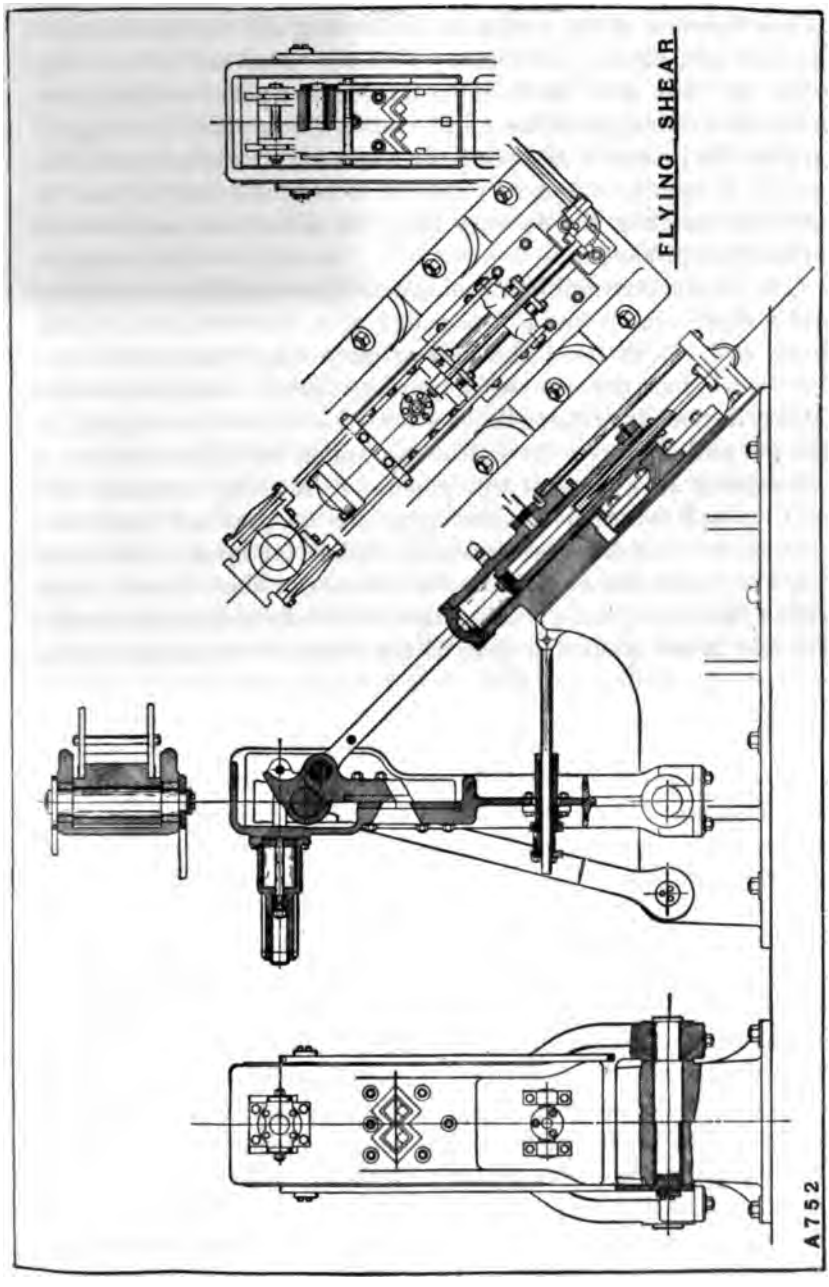

FIG. 13.—FLYING SHEAR.

was designed by an associate of the writer. *Cutting in transit* is the function of the machine. It is designed with knives upon a radial arm moving in company with the metal and while acting upon it. The arm returned to its original position allows the continued discharge of the rolled metal, which, striking a trigger, applies the pressure, actuating the shear for a renewed cut. The action is entirely automatic, cutting to required lengths, and is used for handling the delivery from the mill of the heavier sizes of finished products.

The continuous mill had been applied to miscellaneous rolling but a short time before it was called upon for service in rolling hoop and cotton tie. The mill adapted itself perfectly to the new work, but the *accessories* at once came into prominence. Heavy devices for cutting billets were of little service in handling the flat and limp red-hot cotton tie, which had about as much consistency as a piece of wet paper. Devices for automatically cutting and coiling were first used, but the practice finally settled upon a looping distribution of the metal upon a travelling table or apron, somewhat after the manner of the old floor delivery of wire rods, except being done uniformly and mechanically. By this means gradual cooling of the flat steel was secured without contact of the metal with itself, thus ensuring a uniform blue finish desirable in some varieties of flat rolled products. This was designed by the inventor of the flying shear.

I have referred to the influence of great production upon the development of the mill and its accessory. It is worth perhaps a passing note to speak of the influence upon them of economy and refinement.

Economy and Refinement.

There is a seeming incongruity in the application of eternal laws to a rolling mill, yet the Divine command to "gather up the fragments that remain, that nothing be lost," must be here implicitly obeyed. Economy in fuel consumption, scale waste, and crop ends has usually had *some* attention; but as precision and refinement in finished product and demands for something better and cheaper grew, *economy* grew with them. Economy in moving, in lifting, and in carrying. Economy in using air and water, for, free as they are, yet at high pressures they are costly luxuries, to be used with economy only. In all these economies accessories played a part.

The foundryman's plea that half the machine is built in the foundry is true; with this amendment, that part of that half is built at the forge and mill. We no longer "*allow plenty for finish*," be it machinery steel or foundry casting. Casting and rolling must be done with reasonable exactness. The roller's old worn gauge is now an inmate of the museum. It is the *micrometer* he now must use. He stands between "*limit gauges*." Thus far can he roll, but no farther, and hundredths and thousandths are units familiar to his ear. The result is nicety, refinement, and economy everywhere, and the mill and its accessory must be designed to meet them.

A recent accessory of the merchant mill—a storage system—has been designed by the writer's associates, the whole function and purpose of which is *economy*. Economy in time, economy in material. Ordinarily a jobbing merchant mill runs on part time—its use is intermittent, depending upon the receipt of orders and the lengths and quantities of the material required. This intermittent use of the mill has been demoralizing to the whole plant. Aside from the loss upon idle and unproductive equipment, there has been the direct loss and expense of frequent roll changing and adjustment in filling small and miscellaneous orders. The *continued* use of the mill for products carried in stock has been prohibitive by reason of the great waste from crop ends. *Length* of merchant bar, like that of the original wire rod, has been determined by the vehicle for transportation—one by the length of the freight car, the other by that of the farm wagon. Cutting the varied lengths of commerce from these ordinary merchant-bar lengths has been highly wasteful of large quantities of valuable metal. To obtain relief from these extravagances—*i. e.*, idleness of the mill and waste of material—the storage system has been evolved. By its use the finished piece, straightened, cooled, and *uncut*, is carried laterally to storage racks having compartments of large capacity in which standard sizes and sections are kept separately and in stock. Shearing facilities are placed at each end of the racks, and most of the cutting is done only upon receipt of orders, and then to specific or multiple lengths. As a result there is a saving of metal, a saving of time, a more continued use of the mill, and an enlarged efficiency by greater freedom in the use of heavier billets.

Continuity.

No single aspect of modern manufacturing is more striking and pronounced than the drift towards continuity of operation. Not that of the continuous mill alone, although that mill has done its full share; but everywhere, in all lines of work, the search for economy and despatch has weeded out slow and needless intermediaries and unified functions before separate and distinct. Operations which heretofore hindered and delayed have now disappeared from the continuous mill, until it is a familiar sight to see a billet, one end still in the furnace—its length in all the reducing passes of the mill, and the other end coiled on the reel, a finished wire rod—a continuous and simultaneous performance of heating, rolling and reeling upon the same piece of metal without cut or separation of its parts. No less striking is the operation of rolling *larger* sections. The metal, a few moments ago a 6,000-pound ingot, and now a four by six-inch billet, is carried onward to the mill, a part of its length moving on the feed table, part moving faster through the passes of the mill, part being cut by the "flying shear," part caught up and carried away on the conveyor, and part being delivered on the car for transportation from the mill.

Here again are parts of the same mass of steel being fed, rolled, cut, conveyed and delivered, continuously and simultaneously. There is something a bit dramatic in the sight of a bar resting on the car ready for shipment, while the parent from which it sprung is still away back in the bite of the roughing rolls.

So it is everywhere. Be it the making of a newspaper or an envelope, from roll to finished product—folding, cutting, printing, stamping, and counting—it is continuous to the end. It is in the very spirit of the times—quickness, continuity, and economy. In a recent review of the astronomy of the century, Professor Dolbear, of Tuft's College, drops a little sentence, "Creation is a *continuous* process." If the scientist finds creative processes continuous in *his* domain, no less so does the engineer find it *in his own.* Creation of the *raw materials* upon this planet has been a continuous process, and so is fast getting to be the creation of the *finished products* from them.

Wealth of the Country.

In conclusion, then, may I ask, What has the rolling mill been worth to our country? Over a hundred years ago (as we have

seen) one of England's statesmen, in substance, said it was worth to that country more than the whole of certain thirteen colonies. What has it been worth to those colonies? *What has it done for them?* Vastness of the question makes brevity of reply. Who can measure, estimate, or enumerate the indebtedness and dependence of the nation to the offspring of the "little mill at Fontley"? There were the colonies strung like a filament along the eastern shore, and all that great work to the westward to be done. To tunnel mountains, dig mines, bridge rivers, lay rails, fell forests, sow, reap, and ship the grain. It was a task enough to daunt the bravest. Watt's Hercules lent its strength, but the rolling mill put into his hand a club of "ever increasing might" with which to "batter down the institutions of preceding ages," and Hercules needed all his strength to swing it. I know it suggests the old spirit of "Who shall be greatest?"—the rivalry of coöperating and interdependent parts—but it was rough justice that awarded Solomon's blacksmith the honored chair. Why not this tribute to his successor—the rolling mill of to-day? How far would we have gone, and how much would we have done without it? With each new demand the mill has been equal to the occasion. Transportation and communication, the vanguard of all civilization, would have been helpless without it, to say nothing of all the every day dependencies upon it. Particularity of these would be but tedious enumeration. Its work is in the web and woof of all we do.

The steamer going East and the railroad going West are built and burdened with the products of the mill. How much of the great West, and all the wealth which is in it, would have been ours without the help of the rolling mill?

There come to mind the doubting and uncertain days when the far West lay too big and boundless to be understood—when the mind of the statesman, Webster, could not grasp it—would not vote "one cent from the public treasury to place the Pacific coast one inch nearer to Boston than it is now," and was "about trading that worthless territory for some valuable concessions in relation to the cod fisheries."

Those were curious days in the light of to-day: when the appraised value of the West was expressed at Washington in such figurative terms as "interminable desert," "arid plain," "impassable mountains," "not worth a pinch of snuff," "region of savages and wild beasts," "deserts of shifting sands, dust, cactus, and prairie dogs."

And so it was, and so it would be now, but for the products of the rolling mill.

One statesman said: "Have you made an estimate of the cost of a railroad to the mouth of the Columbia?" "How are you going to apply steam?" The rolling mill has solved his problem and answered his question.

Another statesman, in similar vein, said: "All the gold of Peru would not pay a penny on a pound of the cost it would be to build a railroad over the mountains to Oregon." Well, probably it would not if the rails for the road were all forged under the old tilt hammer in use before Cort's time.

Has it paid to cross the mountains? Mountains "impassable for wagon roads" until the undaunted spirit of Marcus Whitman found the trail and blazed the pathway for us. Last year the iron horse, harnessed in the trappings of the rolling mill, and shod with its products to give it foothold, drew from these "impassable mountains" one hundred and seventy millions of gold, silver, and copper! Has it paid?

'Tis the poet's license to use our language in æsthetic sense; I claim the plain man's privilege to use it in the literal. We know whose the strong hand that has made the material welfare of our country. We know, and that right well, "what master laid its keel, what workman wrought its ribs of steel, in what a forge, in what a heat, were shaped the anchors of its hope."

And so it ever will be. As long as human beings come and go, the rolling mill will serve until mankind shall cease to know a physical want unsatisfied, or longing unfulfilled—and that will be when stars grow cold and "the wide firmament is rolled up like a scroll."

No. 869.*

A RECORD OF THE EARLY PERIOD OF HIGH-SPEED ENGINEERING.

BY CHARLES T. PORTER, MONTCLAIR, N. J.
(Honorary Member of the Society.)

THIS meeting, following close upon the death of John F. Allen, seems a fit occasion to give to the Society some reminiscences of Mr. Allen, and of the infancy of high-speed steam engineering.

I am glad of the opportunity to pay my tribute to the memory of a friend, of wonderful engineering genius and insight and noble character. The subject has, too, for me a singular interest, as affording a prominent example of incidents which occur in the life of everyone, when events trivial in themselves are afterwards seen to have been big with consequences.

One morning in the winter of 1860–61, Mr. Henry A. Hurlbut, then of Swift, Hurlbut & Co., wholesale dealers in hats, at No. 65 Broadway, and who had become interested in my governor manufacture, called upon me to tell me that a friend of his, Mr. Henry A. Burr, manufacturer of felt-hat bodies, at the corner of Frankfort and Cliff streets, in New York, had been having trouble with his engine. He thought my governor was just what he needed, and asked me to accompany him to Mr. Burr's office, where he would give me the advantage of his personal introduction. In the interview with Mr. Burr which followed, I did not have an opportunity to say a word. After Mr. Hurlbut had explained the object of our visit, Mr. Burr replied that he had had a great deal of trouble with the regulation of his engine, and had thought seriously of getting a Corliss engine in the place of it; but, two or three weeks before, the builders of the engine had sent him a very skilful engineer, and since he came there had been no further trouble, so he should

* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

not need my governor. He invited us to see his engine, in which—since it had been taught to behave itself—he evidently took much pride. We found a pair of beam engines of about 5 feet stroke, running at 25 revolutions per minute, made by Thurston & Gardiner, of Providence. They had the usual poppet valves and the Sickles cut-off. This was made adjustable, and was regulated by the governor. At the time of our entrance, Mr. Allen, the new engineer, was on the scaffold, lubricating the beam centres. Mr. Burr called him, and he came down, and at Mr. Burr's request explained to us the liberating mechanism and what he had done to make it work satisfactorily. The regulation did not appear to me to be very close, and I made a determined effort to induce Mr. Burr to substitute one of my governors. I showed him a cut of the governor, and pointed out its combination of power and sensitiveness, but all in vain. He was satisfied with things as they were, and I went away crestfallen, having lost not only the sale of a governor but also an opportunity for a triumph in a very important place. But I did not know to whom I had in fact been talking. As we were leaving, Mr. Allen asked me if I would call some time and see him—he had something he thought I would be interested in. I called soon after. He told me he had a plan for a variable cut-off, with positive movements, which he thought would avoid objections to the liberating gear. He had had it in his mind a good while, but did not think it could be used, because the governor could not handle the block in his link so as to maintain steady motion, and he had been inclined to abandon the idea; but when he heard me describing my governor to Mr. Burr it occurred to him that that governor would do, and he would like to explain the plan to me. He had no drawing, not a line; the design existed only in his mind. He put down his ideas, as he fitly expressed it, with chalk on the engine-room floor, and that rude sketch represented the perfectly matured system.

When his plan came to be analyzed, it was found that everything had been thought out and provided for, even to equalizing the opposite port openings, and compensating for the unequal piston motion produced by the vibration of the connecting-rod, so as to make the opposite diagrams identical. But the wonder did not stop there. Mr. Allen had remedied the defect in the link motion of making a narrow opening for admission when cutting off early, by employing a four-opening admission-valve

of unique design at each end of the cylinder, and also by greatly enlarging these openings.

The four-opening valve required four seats in one plane, and it was important that these should be as narrow as possible. For this purpose Mr. Allen employed the Corliss wrist-plate movement to reduce the lap of the valve, and, by an elegant improvement on this movement, he made it available also to enlarge the openings. This improvement consisted in the employment of two rockers having a common axis, and separate driving-arms, as well as driven-arms, for each valve. The driving-arms were made to vibrate a long way towards their dead points, and the increased opening movement in arc thus obtained was imparted directly to the valve. This combination of an enlarged opening with a reduced lap was, perhaps, the most surprising feature of Mr. Allen's system.

The four-opening equilibrium valve, soon afterwards invented by Mr. Allen, required but two seats in one plane. The seats could, therefore, be made wider. For the sake of simplicity, this division was then dispensed with, and the same enlarged openings were obtained by increasing the length of the driven-arms, submitting to the increased motion on the lap.

That this remarkable system of parts and movements should have been elaborated in the mind of a man who had no knowledge of mechanics, except what he had absorbed in engine rooms, must stand among the marvels of inventive power.

After Mr. Allen had explained his plan to me, I expressed my confidence that my governor would meet its requirements, and observed that it would enable a variable cut-off engine to be run as fast as a locomotive. Somewhat to my surprise, he replied that he wanted his cut-off compared with the liberating cut-off turn for turn; that it had an advantage which he thought would cause it to be generally preferred at the same speed.

I was then ignorant of his state of mind on that subject, or of what had produced it. I learned these afterwards, and will state them here. In one of our interviews, in reply to my question what had led him to make this invention, he told me it was his experience when he was engineer of the propeller *Curlew*, a freight boat running on Long Island Sound, between New York and Providence, which had a Corliss engine. He became impressed with what he thought to be a serious defect in the liberating system. The governor did not control

the point of cut-off, but the point of release; this point being at the beginning of the closing movement of the valve, while the cut-off took place at the end of that movement. When the engine was worked up to nearly its capacity, as was the case in a ship, the port was opened wide, and quite an appreciable time elapsed between the release and the cut-off. During this interval, the piston advanced considerably, and if the engine ran fast enough, it might get to the very end of the stroke. He said in smooth water they had no trouble, but in the open ocean going around Point Judith, it was always rough, and sometimes in stormy weather the screw would be thrown quite out of the water, and the engine, having no fly-wheel, would race most furiously. The faster it ran, the further the steam would follow, and was pumped out of the boiler very rapidly. Springs were employed to accelerate the closing movement of the valves, but in these cases they seemed to be of little use, and were continually breaking. He saw that this difficulty could be avoided only by a positive motion gear which would enable the governor to control the point of cut-off itself; and, accordingly, he set himself to work to devise such a system. We know now that this judgment, formed from observations made under very exceptional conditions, was not well founded. The difficulty in question does not practically exist in engines having fly-wheels and the present improved liberating gear; but the experience naturally made a deep impression upon Mr. Allen's mind, and led to the invention of the positive motion system.

This he did not tell me at the time, so that I was at a loss to understand his reluctance to admit what was really the great value of his invention. However, I told him I would be willing to attempt its introduction, provided he would allow me to apply it at once to a high-speed engine; that being a field into which the liberating system could not enter. To this he assented, and I took him directly to the office of Mr. Charles B. Richards, now Professor of Mechanical Engineering in the Sheffield Scientific School of Yale University, who then had an office on Nassau Street, where he was doing business as a mechanical expert and designer of machinery, and who had done some excellent work for me. I engaged Mr. Richards to make an analysis and drawing of Mr. Allen's system under his direction, and soon afterwards gave him an order for the plans for an experimental engine, 6 inches by 15 inches, to make 160 revolutions per minute.

The subject of an indicator directly presented itself. Mr. Allen invited Mr. Richards and myself to his engine room, and took diagrams for us with a McNaught indicator. This was the first indicator that either of us had ever seen. Indicators were then but little known in this country. The Novelty Iron Works made a very few McNaught indicators, almost the only users of which were the Navy Department and a few men like Ericsson, Mr. Stevens, Mr. Sickles, and Mr. Corliss. I told Mr. Richards that we must have a high-speed indicator, and he was just the man to get it up for us. He went to work at it, but soon became quite discouraged. He could not see his way. I told him I was not able to make any suggestion, but the indicator we must have, and he had to produce it. After some months he handed me a drawing of an indicator which has never been changed, except in a few details. This important invention, which has made high-speed engineering possible, came from the hands of Mr. Richards quite perfect. Its main features, as is well known, are a short piston motion against a short, stiff spring; light multiplying levers, with a Watts parallel motion, giving to the pencil very nearly a straight line of movement; and a free rotative motion of the pencil connections around the axis of the piston, which itself is capable of only the slight rotation caused by the compression or elongation of the spring. Elegant improvements have since been made, adapting the indicator to still higher engine speeds; but these have consisted only in advancing further on the lines struck out by Mr. Richards. In fact, this was all that could be done—giving to the piston a little less motion, lightening still further the pencil movement, and making the line drawn by the pencil more nearly a straight line.

I took Mr. Richards's drawing to the Novelty Iron Works and had an indicator ready for use when the engine was completed. The engine was made by the firm of McLaren & Anderson on Horatio Street, New York. It was set up by the side of their throttle-valve engine, and was substituted for it to drive their own machinery and that of a kindling-wood yard adjoining for which they furnished the power. It ran perfectly from the start, and saved one-half of the fuel. In throttle-valve engines in those days the ports and pipes were generally so small that only a part of the boiler pressure was realized in the cylinder, and that part it was hard to get out, and nobody knew what either

this pressure or back pressure was. I have a diagram taken from that engine, which is here reproduced.

The success of this engine was such that I determined to build a larger engine for the approaching London Exhibition of 1862, and the next May found an Allen engine, 8 inches by 24 inches,

DIAGRAM TAKEN SEPTEMBER 13, 1861, FROM THE FIRST ALLEN ENGINE BY THE FIRST RICHARDS INDICATOR.
ENGINE, 6 INCHES BY 15 INCHES, MAKING 160 REVOLUTIONS PER MINUTE.
THIS CARD WAS RUN OVER TWENTY TIMES.

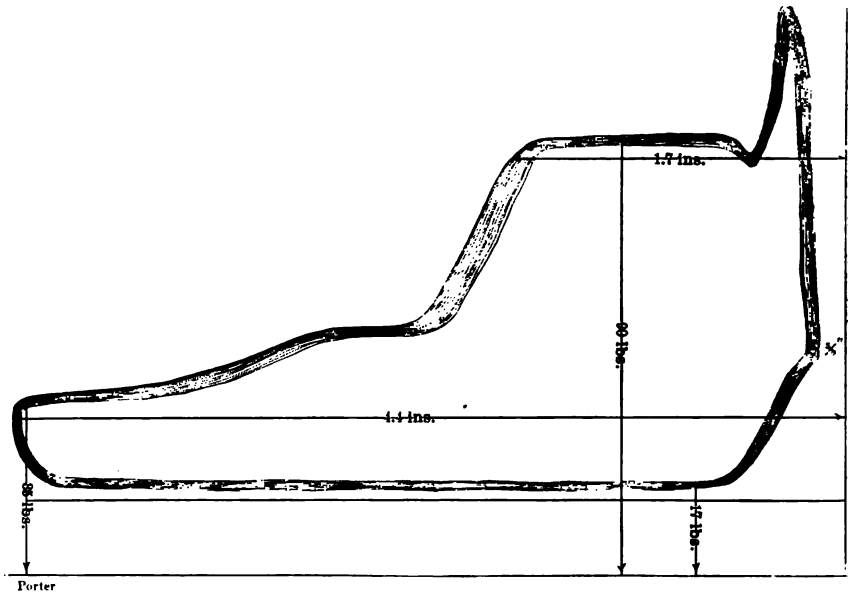

FIG. 14.

making 150 revolutions per minute, in operation in that exhibition, with a success which is a matter of history. The following diagram was taken from that engine.

I found myself in queer company, and I afterwards learned why. There were twenty-four engines in the exhibition, mostly English, all small and all non-condensing, as no water for condensing purposes was obtainable in the locality. That, however, did not strike me as odd, for I had never seen a condensing engine in any public exhibition. They were all quite inferior, what the English would call "a rum lot." A large battery of boilers was unable to maintain the steam pressure, which had been fixed at 70 pounds on the square inch. Especially when

the Gwynne centrifugal pump was running the pressure always fell a pound a minute, so that it never was allowed to run over 15 minutes at a time. Mr. Allen came over in the fall, and soon after his return he sent me a drawing of his equilibrium 4-opening valve and adjustable pressure-plate, which completed his design, according to which the engines have since been made.

I was enquired of by the eminent firm of Easton, Amos & Sons—whose works were located in the Borough of Southwark,

INTERNATIONAL EXHIBITION, UNITED STATES DEPARTMENT.
1862 DIAGRAM TAKEN FROM 1862
THE ALLEN ENGINE BY THE RICHARDS INDICATOR.
ENGINE, 8 INCHES BY 24 INCHES, REVOLUTIONS PER MINUTE, 150.
SCALE, 40 LBS. TO THE INCH.

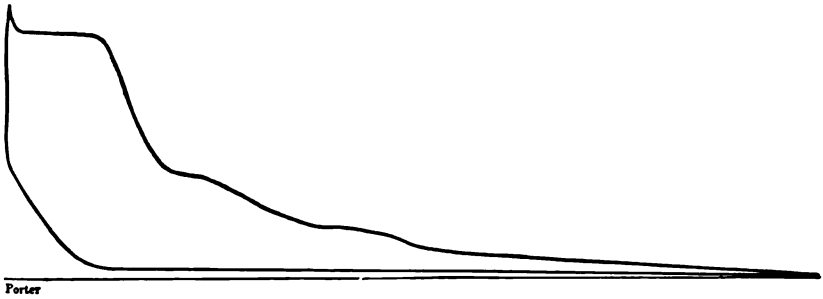

FIG. 15.

in London, a region which Dickens has made famous, who were the consulting engineers of the government, and were builders, and I believe at that time the only builders in England, of compound engines on the Woolf system—if I considered that it would be safe to run my engine at 225 revolutions per minute. Of course I knew no more about it than they did, but I did not hesitate to say that in my judgment it would be perfectly safe. On the strength of that "opinion" they purchased the engine, and set it up in their own works to drive their foundry blower through a frictional gearing, 9 to 1. It fully justified my opinion, and did this work so easily that I proposed to them to use it to drive the whole works. Everything there was compact in a degree to which we were not accustomed. The foundry was separated from the machine shop only by a brick wall, and the boilers were on the main floor of the machine shop itself. The engine got along pretty well until they were grinding shafting

with large grindstones at the same time that the foundry blower was on. That was too much for it, because the addition of 50 per cent. to the speed had made the ports and valve movements very insufficient. However, they gave me a portion of the works to drive.

The year 1863 was devoted by me partly to the introduction of the indicator and partly to the revision of the engine plans, including the introduction of the equilibrium valves. Among other things, I designed the present engine bed.* The manufacture of the engine in England, according to these revised plans, was commenced in January, 1864, by the firm of Ormerod, Grierson & Co. of Manchester. In the year 1866 this firm failed, and on the invitation of the Whitworth Company I transferred the business to them.

The Whitworth Company sent to the Paris Exposition of 1867 four Allen engines, and also a sectional model, the latter being a complete small engine with the upper half of the cylinder and steam chest planed off, showing the valves in section, all being exhibited in slow motion. Three of the engines were 6 inches by 12 inches. Two of these were employed to drive an electric apparatus for the British Lighthouse Board, and were run at 300 revolutions per minute. The third was run idle at 500 revolutions per minute, to illustrate the adaptation of Mr. Allen's system to very high speed. For this illustration careful preparations were made. The fly-wheel was a light solid disk, 2 feet in diameter. The reciprocating parts weighed only 40 pounds, and were exactly balanced by the counterweight. The bed was filled with lead. The whole was set on a single block of Caen stone 3 feet thick. This engine was shown, for one or two minutes several times a day, at its top speed by holding up the end of the governor lever, so bringing the block to the top of the link and letting it hum. It ran, as nearly as could be judged, at over 2,000 revolutions per minute. When the governor resumed control and the speed slowed down to 500 revolutions, it always seemed to the bystanders as if the engine were going to stop. The fourth engine was 12 inches by 24 inches, making 200 revolutions per minute, and driving a portion of the English machinery exhibit. This was a condensing engine.

* This bed was adopted by Tangye Brothers, of Birmingham, several years afterwards.

At the London Exhibition of 1862, one of the first questions asked me, and which I heard often afterwards, was: "How do you drive your air-pump?" The form of the question, it will be observed, assumed that, of course, the engine had an air-pump, which it was understood could not be used there. At first, I innocently replied that the engine was a non-condensing engine, and had no air-pump, little aware of the effect this answer had on the mind of the questioner. After a while I became by degrees conscious that I was among conditions and habits of thought very different from those to which I had been accustomed. The fact was, that, from an engineering point of view, to the English mind a non-condensing engine was no engine at all. They were always simple and cheap engines, built mostly for export—commercial goods only. All engines of the least consequence in England were condensing engines, and as my engine claimed to be at least respectable, it must have an air-pump, of course. As my destitution in this respect became known, I came perilously near to being dropped, without ever knowing why.

Easton, Amos & Sons frankly expressed to me the consensus of engineering opinion, that high speed, while successful in non-condensing engines, was not to be thought of for condensing engines. In the then existing state of the art, this condemnation was unavoidable. The air-pump must run with the engine, stroke for stroke. At high speed it would lose its efficiency for two reasons. The valves would not seat themselves in time, and the air and water would be churned into foam. The question with which I had become so familiar, slightly changed to the form "How are you going to drive your air-pump?" was before me, imperatively demanding an answer.

I wrestled with this problem all the while I was with Ormerod, Grierson & Co., and, when I went to the Whitworth Company, had a design ready to be put in execution.

This condenser was planned on a somewhat new constructive principle. It was a square box, set behind the engine and divided into three compartments, one occupying the lower and two the upper half. One of these latter was the condenser and the other the hot-well. The bottom of the condenser was inclined slightly downward from the hot-well. The valves were large, with a short lift, and were closed by springs.

In the lower chamber was a single acting ram, connected with an extension of the piston-rod, and working in a body of water.

It was hollow, floating in the water, and pointed so as to move through without disturbing it. The areas were such that a motion of the ram of one foot produced a rise or subsidence of the water of one inch. The air, it will be observed, remained above the water, was drawn in last and expelled first. There was no place where a particle of air could be trapped.

It being evident that this condenser would answer, I put three of them in hand at once, for three engines to be run at 150 revolutions per minute, and, there being no alternative, I sent the first one which was ready to Paris, to be tested in the Exposition; and moreover, determined to settle the question decisively as to the adaptation of high speed for condensing engines, I put the speed of that engine up to 200 revolutions per minute, and I had the best vacuum in the Exposition, where several condensing engines were shown, some very large.

The gauge stood always between 28 inches and 29 inches. This condenser was not patented. Twenty-five years after I learned that it had come into general use in Europe.

The French engineers would not accept the reality of this vacuum unless it should be shown by a Deluel mercurial gauge. So I went to the establishment of Deluel & Co. and obtained a gauge, and the same night drilled the condenser to put it on; but no tap could be found to fit the thread. I had to plug the hole, and went the next day to the Deluels with my complaint. They very politely loaned me a set of taps, informing me, with the greatest apparent satisfaction, that this was a thread peculiar to their house. The new gauge agreed exactly with the old one, a Bourdon gauge, and the French engineers were satisfied.

The following diagram was taken from this engine. It is the only one from both ends that I have preserved, and was drawn on double the usual scale.

The inequality of the opposite diagrams is due to the change of load while the instrument was being transferred from one end of the cylinder to the other.

The port areas and valve movements were insufficient, but they were designed for a speed of 150 revolutions per minute.

The Richards indicator at 200 revolutions, and with a 16 pound spring, drew a waving line. The vibrations interested me. The lines being flowing showed an absolutely frictionless action. I could touch the pencil to the paper so lightly that the vibrations would continue to the end of the return stroke, or could

press it so hard that they nearly disappeared, but their mean was always the same.

This exhibit produced a marked impression. Mr. John Hick of Bolton, since head of the firm of Hick, Hargraves & Co., and, then the largest builder of stationary engines in England, spent

EXPOSITION UNIVERSELLE, PARIS, 1867.
DIAGRAM FROM THE "ALLEN" ENGINE, EMPLOYED IN DRIVING MACHINERY IN THE BRITISH SECTION, AND MANUFACTURED BY THE WHITWORTH COMPANY, LIMITED, MANCHESTER.
ENGINE, 12 INCHES BY 24 INCHES, REVOLUTIONS PER MINUTE, 200.
SCALE, 16 LBS. TO THE INCH.

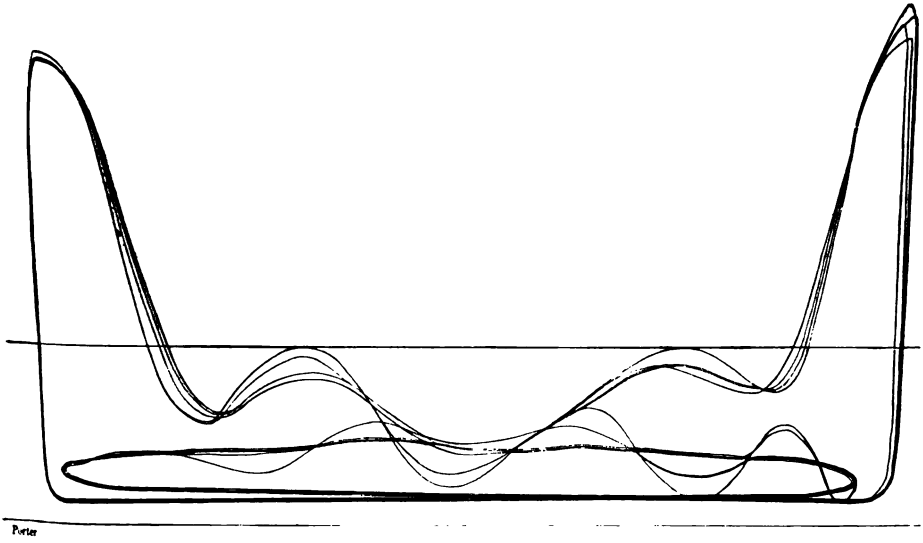

FIG. 16.

a long time every afternoon of his ten days' stay in Paris watching the running of this engine. He told me that no amount of testimony would have made him believe such a performance to be possible. If my engine shown in 1862 had made anything like the same impression on his mind, he would have made me a proposition, but it did not. The idea of employing an engine running at that speed as a condensing engine did not occur to him, and if it had, he would not have given it a moment's consideration. So the engine failed to interest him. He had since made other arrangements, which it was then too late to change.

I received three propositions from French builders. The first two, made nearly simultaneously in the summer, were both

accepted in the autumn, the parties agreeing to work together. I was sorry when this obliged me to decline an application, which came just before the close of the Exposition, expressed in the most complimentary terms, from Farcot et Cie, the leading builders of stationary engines in France, and the largest exhibitors of them at the Exposition, after they had observed the running of the engine for nearly seven months.

Mr. Allen was sent over to Paris by the parties interested in the United States, to examine for himself what was being done and report to them. His report was so satisfactory that I was written to, to leave everything abroad in the best condition I could, and return home to engage with Mr. Allen in the manufacture of the engine, for which ample capital would be furnished. I found, however, that the financial provision made for turning to account the position which I had gained was ridiculous, while both the shop, which I found already started, and its location, on Fourth avenue, in Harlem, were equally absurd; especially when, some four years later, the railroad was put in a trench on that avenue, and each side of it was occupied for more than a year by temporary tracks in constant use by three roads, cutting off all communication with the premises; but as nothing better could be done, we struggled along in a small way with meagre facilities until the great financial revulsion of 1873 found the business in excellent condition to be abandoned.

During this period Mr. Allen gave to our business the last contribution of his inventive skill. We had discussed the subject of water-tube boilers quite fully, and considered especially the Field internal circulating tube. One day Mr. Allen said to me that he had an idea that by inclining the tube at a small angle from the vertical position, a better circulation could be got than from an internal tube. This proved to be an inspiration of genius, which, in my judgment, will form the fundamental feature of the water-tube boiler in its finally perfected and surviving form.

In 1871 Mr. Allen, wearied of our absurd position, and also, as is often the case with genius, longing for new worlds to conquer, sold out his interest in the engine business, and devoted himself thereafter to the development of the pneumatic riveter and the air-compressor. My acquaintance with this latter part of his career is not sufficient to enable me to speak of it as definitely as others can do.

Mr. Allen's locomotive valve was presented in a paper by Mr. Quereau, at the late Washington meeting. In the discussion of that paper, I omitted to state that the value of balancing that valve—as, indeed, every locomotive valve—was fully realized by Mr. Allen. In plans for that valve made by myself, a free balancing ring was shown on the back, having an internal area equal to that of the exhaust cup, and communicating with it.

I may perhaps be pardoned for a word respecting the change of name of the engine. I was sometimes asked by my friends what I had to do with the Allen engine. It occurred to me that I had considerable to do with it. So when, after a suspension of three years, I was about to resume its manufacture in its finally matured form, to be carried on by myself individually, it seemed not only proper, but also demanded in the interest of the business, that it should be revived as the Porter-Allen engine.

In my intercourse with Mr. Allen I was always impressed with the depth of his penetration, and the general soundness of his judgment. He lived in a region of engineering and mechanical principles, with which his familiarity was certainly intuitive. Deprived of all early advantages, the world gave him nothing, but he will be counted among those who have given much to the world.

DISCUSSION.

Prof. R. H. Thurston.—Mr. Porter's paper has for me, naturally, a peculiar interest. Personally acquainted with the men mentioned, having a very long acquaintance and a strong friendship for the men most prominent in the matters described, and having had, myself some part in the changes of that time, I may be pardoned a word of comment.

The engine at the Burr "Hat Factory," as we used to call it, was built by my father, then the senior member and the superintendent of the firm of Thurston, Gardiner & Co., and I, a boy in college at the time, had something to do with its construction; for my vacations and holidays were usually spent at the shops and in the draughting rooms of the establishment, then the most extensive in New England, I think. I remember the engine well, and our difficulties in securing regulation of the Sickles cut-off. Engines which we were then building were usually governed by a Watt governor and throttle. The attachment of the governor to determine the point of cut-off was only com-

menced after Corliss had led the way—or rather after Zachariah Allen, in 1835, had shown a way which was not seriously considered by engine-builders until after Corliss made the system an integral part of his own. I well remember building a Watt governor with balls of *eighty* pounds weight, about 1859, to regulate a rolling-mill engine of the time with a Sickles valve-gear. We never succeeded in getting good regulation until we brought out the Greene engine.

I knew Mr. Allen well in those days. With my father, I had visited him on the *Curlew* and heard the story of his difficulties with his engine from his own lips and his hope to find a way to improve on the system. The ship was one of several which Mr. Corliss fitted with his engines, hoping to secure a marine trade; but none were satisfactory, and the engine never came into use at sea; notwithstanding the fact that its predecessor, the Sickles engine, had found a somewhat extensive employment—always, however, I think, on sidewheel boats, where the difficulties which annoyed Mr. Allen were not met with in any important degree. Mr. Corliss made the mistake of assuming that his valve-gear would operate with certainty and accuracy at any speed of engine, even in locomotive work, and he actually built a locomotive—which Holley immortalized—with his cut-off gear attached. That engine stood a long time in Corliss' shops, where I saw it a number of times.

When we had our little difficulty with the Burr engine, we were confident that Mr. Allen was just the man to meet it, not simply because he had had a very large experience with troublesome valve-gear, but, and mainly, because he was thought the ablest man in his department of the business known to us. He was steady, reliable in all ways, ingenious, experienced, thoughtful and always ready in cases of emergency with some expedient capable of meeting the need of the moment. Mr. Burr, also, was a somewhat critical man, and it was thought that Mr. Allen was just the person to work well with him. The judgment which selected and detailed him was fully justified. From that time on, I always kept him in sight and watched his career with the greatest interest and pleasure. He was a great mechanic and an admirable man; he led a most useful life and earned much greater distinction and a larger reward than he ever received. My father, who died in 1874, always congratulated himself that he was instrumental in bringing about that

turn in Mr. Allen's path which gave him his largest opportunities.

I had the pleasure of making Mr. Richards' acquaintance in 1861; although I am not sure that I had not met him earlier in some incidental way. I had always been much interested in the perfection of the steam-engine indicator, and one of my boyhood's amusements was the use of the indicator during my high-school and college days in the investigation of the action of engines, old and new, but particularly old and badly adjusted, and I had an old Hopkinson indicator of the middle of the century, or earlier, and a McNaught which I had used with entire satisfaction on the slow-moving machine with which I was brought up and sometimes to my own confusion and the mortification of our designing engineers. For example, I showed an engine, built for a mill at Wickford, R. I., to be twice as large as it need be for the work, and was, in compensation for my discovery, set at work designing a reinforcement of its flywheel, of equal weight with the original wheel, to give it better regulation. I was attached, in 1861, to the gunboat "Unadilla," of the United States Navy, the first of the gunboats built by the government after the outbreak of the civil war. Mr. Richards and friends came to the ship with one of his then new indicators, and we tried the instrument on engines built to turn at the then very high rate of 100 revolutions per minute, and with entire success, of course. As Mr. Porter has said, that improvement embodied the essentials of all later instruments of the class—a very light piston, with short movement and stiff spring, and a multiplying parallel-motion system to operate the pencil over a longer range than was traversed by the indicator-piston. It may be interesting to observe the evolution of the indicator, comparing the successive forms as in the figure, in which I have grouped from our collections those which I have mentioned for comparison with contemporary constructions. (Fig. 17.)

The incident was, to me, very impressive and I made the acquaintance of a man, as the outcome of it, endowed with rare genius as well as rare personal virtues. His services in this and some other directions, to the profession and to the world, should never be forgotten.

Still later it happened that I had occasion and opportunity to meet Mr. Porter and Mr. Allen under interesting conditions. They brought their engine and their new boiler to the Fair

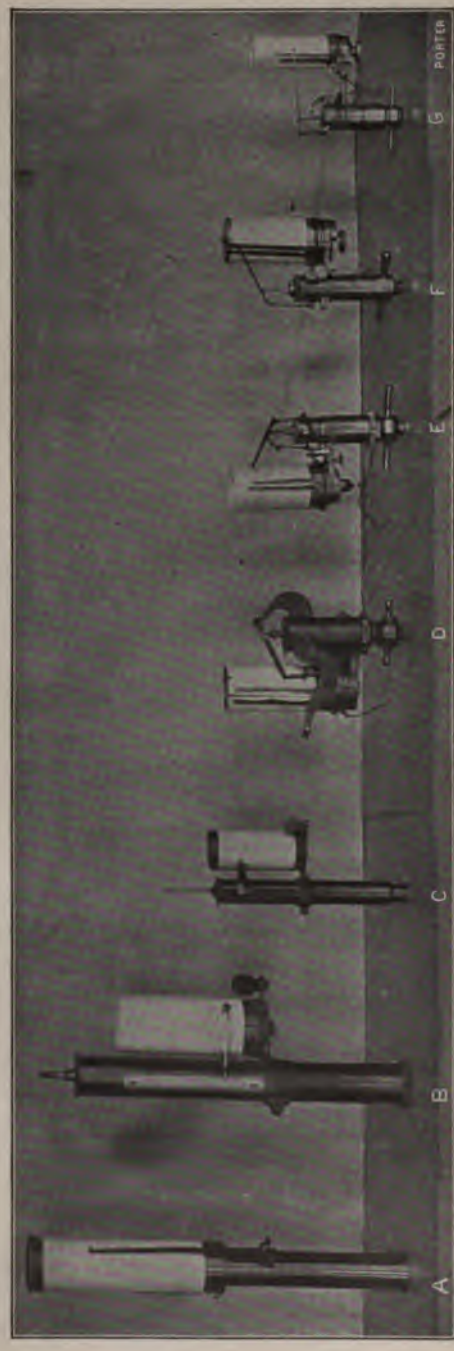

FIG. 17.—THE EVOLUTION OF THE "INDICATOR."
A, Hopkinson; *B*, *C*, McNaught; *D*, Richards; *E*, *F*, *G*, later forms.

of the American Institute while I, as a manager, had more or less supervision of the mechanical portion of the exhibition. It was there that we first had opportunity to see and to test the new boiler, with its peculiar system of pendent tubes. It was reported upon as one of the boilers tested in the first, perhaps the only, trial in which the quality of the steam produced was ever completely determined, not by sample, but by actually condensing the whole output of the boiler in a large surface-condenser built for the occasion out of tubes furnished by Mr. Root, who, with Mr. Porter, was most active in securing this essential datum. I have a copy of the report of the committee of that exhibition in this department still, and find in it the record of the Allen boiler as No. 1 in capacity and No. 3 in economy of fuel, as tested, with a 70.7 per cent. of economical effect, as against 70.9 for the Root boiler, exhibiting lower capacity, and 75.6 for the Blanchard, a tubular boiler fitted with a special hot-water feed system and superheater, utilizing waste heat from the flues, and thus hardly comparable with the water-tube boilers without these accessories. It proved to be interesting and original in construction and better than its competitors, all things considered, in its combination of capacity with economy of fuel. Its circulating system, so far as then appeared, was all that Mr. Allen and Mr. Porter claimed for it. It is to be hoped that it may be again brought forward and that a place may be found for it in the market. Of the five boilers tested at the time, the two water-tube boilers only gave absolutely dry steam, both superheating their steam about 15 degrees. The report on this trial, which has historical importance as the first boiler trial in which the amount of steam actually made *and its quality* were completely determined, can be found in the Transactions of the American Institute of the State of New York, 1872. Its substance is also given in my own book on steam boilers, as published by the Wileys, as it marks an era in steam boiler construction and use.

The work of Messrs. Porter and Allen, in the introduction of the principle of high-speed engine construction as a source of economies, and their services as pioneers in our contemporary practice, cannot be too highly honored. When they began they found the steam engine in a transition stage, and it was their work largely which raised it to its present satisfactory plane. They did much to give it its present excellence and admira-

ble perfection in adaptation to modern purposes. It was Mr. Porter who first seriously undertook the construction of a steam engine which should be especially designed to take advantage of the obvious economical principle of the high-speed engine, and to introduce it as such in the face of prejudice, conservatism, and habitually defective methods of construction. It was Mr. Allen who first sought to design a valve-gear which should be a positive motion gear, and, at the same time, give a satisfactory steam distribution at all speeds. It was Messrs. Porter and Allen, working hand in hand, who made the high-speed engine a recognized class of marketable and practical construction, and who first built an engine which could be driven up to previously unattainable speeds without sacrificing utterly the desirable steam distribution secured by the previously existing low-speed machines. It was their success in attaining these objects which made the revolution which followed in engine construction for electric light and power plants possible, commercially and constructively. They pointed the way to the profession in this field. It was Messrs. Porter and Allen who exerted such an influence as the world had never before seen in a moral way: showing what could be gained by absolute loyalty to scientific principle and to the highest possible perfection in construction; and I am sure that it will be admitted by all who have seen the changes since their pioneer work began, that this moral influence has been no less important, if not indeed of greater importance, than that exerted in any other line.

No. 870.*

A MECHANICAL INTEGRATOR USED IN CONNECTION WITH A SPRING DYNAMOMETER.

BY MAX H. WICKHORST, AURORA, ILL.
(Junior Member of the Society.)

THE integrator described herein is one designed and gotten up by the author for use in the dynamometer car of the Chicago, Burlington and Quincy Railroad for the purpose of automatically and autographically showing the average drawbar pull or the work performed. The dynamometer apparatus of this car consists of a spring dynamometer, with suitable recording apparatus and recording pens for obtaining a record of the compression of the springs, the distance travelled, the time consumed, and now, also, of the work performed in suitable units, such as mile pounds.

The mechanical integrator consists of a registering wheel, which slides backward and forward in sympathy with the dynamometer springs, and a circular disk, making in this case nearly three revolutions per mile, and on which the registering wheel slides. Fig. 19 shows the recording apparatus with the integrator in position, and the general arrangement is shown on attached diagrammatic sketch (Fig. 20). The registering wheel is a small steel wheel 2 inches in diameter, and the disk is brass, 11 inches in diameter. The wheel is so placed that when there is no compression of the springs the wheel stands on the centre of the disk. Its plane is at all times at right angles to the line of motion of the spring compression. Thus the farther the wheel gets from the centre of the disk, the more revolutions will it make for a given number of revolutions of the disk. The sliding of the wheel back and forth on the disk causes no revolving of the wheel. Only the turning of the disk causes the wheel to

* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

revolve, and in proportion to the distance the wheel is from the centre of the disk.

In the Chicago, Burlington and Quincy car the dynamometer recording pen makes an ordinate equal to twice the compression of the springs, and the wheel slides back and forth in rigid connection with the same bars which hold the recording pen, and thus moves the same amount as the pen. Thus, if the pen make

FIG. 19.

an ordinate of 1 inch, the wheel will make 1 revolution for each revolution of the disk, the wheel being 2 inches in diameter and revolving on the disk 1 inch from the centre. If the disk makes 3 revolutions per mile, the integrator wheel will make 3 revolutions per mile for an ordinate of 1 inch. Then an ordinate of $\frac{1}{3}$ inch for 1 mile causes 1 revolution of the wheel; that is, 1 revolution of wheel in 1 mile is equal to $\frac{1}{3}$ inch ordinate; 3 revolutions, to 1 inch ordinate; 6 revolutions, to 2 inches ordinate; 15 revolutions, to 5 inches ordinate, etc. The work represented by

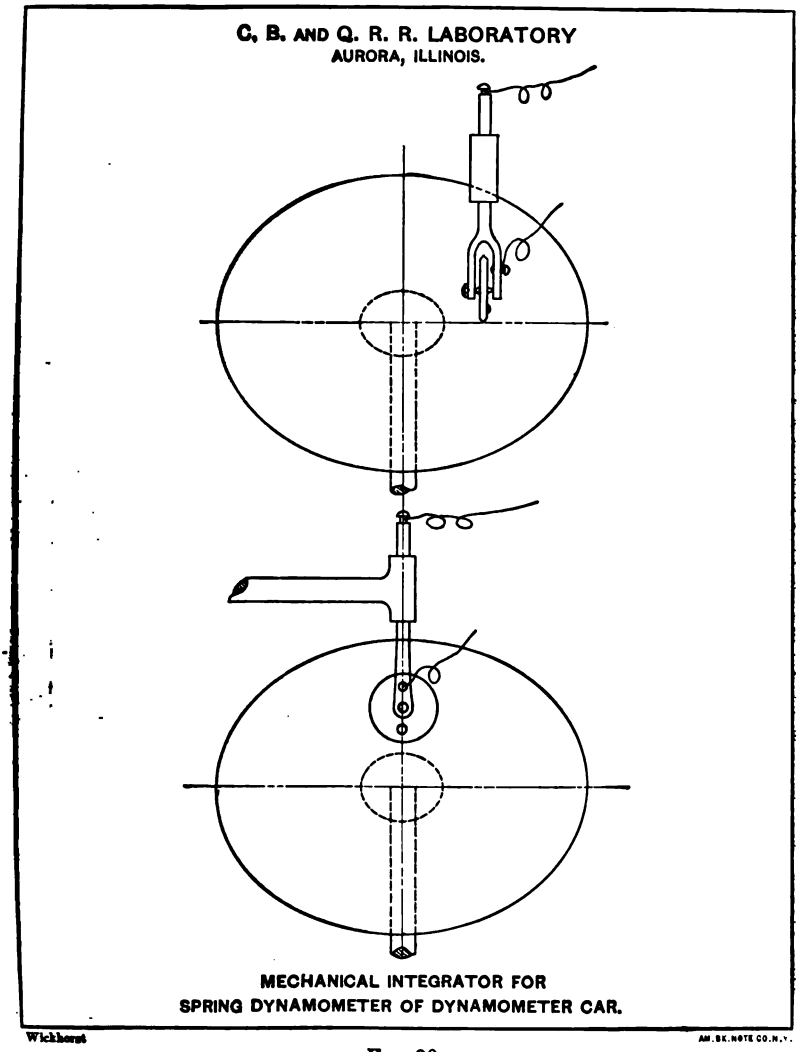
C, B. AND Q. R. R. LABORATORY
AURORA, ILLINOIS.
MECHANICAL INTEGRATOR FOR
SPRING DYNAMOMETER OF DYNAMOMETER CAR.
Wichherst
AM. BK. NOTE CO. N. Y.

FIG. 20.

each revolution of the integrating wheel may be found by the formula shown below.

Let w = mile-pounds of work per revolution of integrator wheel.

o = any ordinate made by pen.

r = pounds resistance for the given ordinate.

i = diameter of integrator wheel in inches.

d = revolutions of disk per mile.

s = space or distance travelled in miles.
p = average drawbar pull for any given distance.
n = number of revolutions of integrator wheel.

Then,
$$w = \frac{r}{\frac{2\pi o}{\pi i} \times d} = \frac{ri}{2do};$$

$$p = \frac{wn}{s} = \frac{rin}{2dos}.$$

Where $s = 1$ mile, $p = wn$.

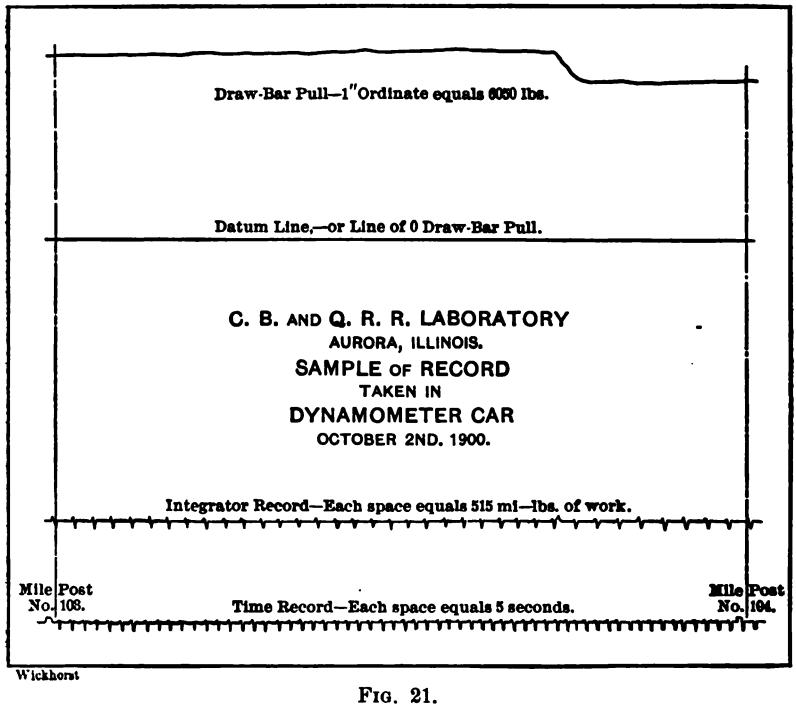
Draw-Bar Pull—1"Ordinate equals 6050 lbs.
Datum Line,—or Line of 0 Draw-Bar Pull.
C. B. AND Q. R. R. LABORATORY
AURORA, ILLINOIS.
SAMPLE OF RECORD
TAKEN IN
DYNAMOMETER CAR
OCTOBER 2ND. 1900.
Integrator Record—Each space equals 515 mi—lbs. of work.
Mile Post No. 103.
Time Record—Each space equals 5 seconds.
Mile Post No. 104.
Wickhorst

FIG. 21.

Our method of recording the revolutions made by the wheel is to let the wheel close an electric circuit every $\frac{1}{4}$ revolution. This actuates an electro-magnet, which in turn actuates a recording pen. Thus, when the car moves, the paper moves under the pen at the rate of 12 inches per mile, the pen making a line, and at every $\frac{1}{4}$ revolution a notch is made in this line. By counting the number of these notches for any mile, and then multiplying

by the proper factor, we get the mile-pounds of work for this mile, and by then dividing by 1, the average drawbar pull.

To show how the integrator record is taken, a facsimile copy, reduced (Fig. 21), of the record taken in the dynamometer car is shown. It will be noticed that this record leaves the integrator readings in such shape that they can be checked by means of the planimeter. Such checkings have shown that with ordinate of 3 or 4 inches the integrator and planimeter results agree within a fraction of a per cent. With small ordinates the differences amount to 1 or 2 per cent., and occasionally more, depending on the care taken to set the integrator wheel correctly on the centre of the disk, where there is no strain on the dynamometer.

Finally, I wish to express my thanks to Mr. P. H. Cummings, who made the necessary shop drawings, and looked after the details of making the instrument, and made many valuable suggestions, and also to Messrs. J. C. Thorpe and E. V. Hanson for their work and suggestions in connection with same matter.

DISCUSSION.

Mr. A. F. Nagle.—If the author of the paper is present, I would like to ask whether he experienced any difficulty with the surfaces of the wheels. I see he used a brass wheel for the disk, and steel for the roller. I would like to know whether he experimented with iron or wooden or paper wheels before he decided to use the brass wheel; whether there was any difficulty with the surfaces of contact between the two wheels.

Prof. Sidney A. Reeve.—I wish to ask the same question. I recently built an integrating transmission dynamometer, or power meter, for practically the same purpose, using a steel wheel running on a brass disk. In the first construction, the integrator revealed serious inaccuracy, due to the slipping of the wheel on the brass disk.

Mr. R. H. Soule.—The author seems to have contented himself with a description of his apparatus; but he does not tell us how the diagram which is made by it may be interpreted. Having had at one time some experience in connection with one of the dynamometer cars in use on the Pennsylvania Railroad, I was curious to pursue this matter a little further and to see whether the diagram afforded a ready means for quickly ascertaining the horse-power which was being developed by the locomotive, say

during any one minute of the run; and if I have interpreted the description of the apparatus rightly, I conclude that it is possible to make a quick and ready reading of the diagrams, and I have prepared some notes to offer in that connection.

The diagram states that each space of the integrator record line represents 515 mile pounds of work. This is equivalent to 2,719,200 foot pounds of work. The horse-power which is being developed by the locomotive under test during any one minute may be computed as follows: As each space on the time record line represents 5 seconds, 12 such spaces will represent 1 minute; take any 12 consecutive spaces on the time line, and erect ordinates at the extremities to intercept the integrator record line; the portion of the integrator record line included between these ordinates will be a measure of the work done by the locomotive in that 1 minute.

Let a = number of spaces on integrator record line included between ordinates from time record line; then,

$$HP = \frac{a \times 2{,}719{,}200}{33{,}000},$$

which resolves itself into the simple equation, $HP = 82.4\ a$; that is, ascertain the number of spaces on the integrator record line intercepted between the two end ordinates corresponding to 12 spaces on the time record line, and multiply by 82.4, and you have the horse-power being developed by the locomotive during that particular minute.

At the left-hand end of the diagram, $a = 8$ (approximately), in which case the horse-power for that particular minute would be 8 times 82.4, or 659.2.

If the integrator record line has the same number of notches as the time record line, then $a = 12$, and $HP = 82.4 \times 12 = 988.8$; that is, very near to 1,000; from which it may be inferred that when the number of notches in the integrator record line and the time record line is the same, the locomotive is developing about 1,000 horse-power at the dynamometer spring.

Mr. Nagle.—Is that horse-power net horse-power or indicated horse-power to be computed from the formula; that is, horse-power at the brake bar?

Mr. Soule.—That, of course, would be the horse-power which was revealed by the dynamometer car through its draft spring,

and would not correspond exactly to the indicated horse-power of the locomotive.

Mr. Nagle.—Will Mr. Soule tell me what he thinks is the efficiency relation between the draw-bar pull and the indicated power of the locomotive?

Mr. Soule.—It is generally assumed, I believe, that the internal friction of a locomotive ranges in the neighborhood of 10 per cent., and you would, of course, have to add something for the tractive efforts being exerted by the locomotive to drag itself, and possibly the dynamometer car, along, although I presume that the dynamometer car would be so set in the train that the recording spring would be at its front end; and then another complication would come in; that is, we would have to consider the question whether the locomotive was operating on a level or on a grade at the particular time when this observation was made. So it is a very hard question to answer; but I should imagine that the horse-power revealed by the dynamometer car would range from at least 10 per cent. to almost any larger per cent. (depending on the grade on which the locomotive was working) less than the indicated horse-power of the locomotive at the same time.

Mr. Nagle.—I have understood that the efficiency of a locomotive, or the relation between the indicated power and the draw-bar pull, is only about 42 per cent. Locomotive men can correct me if I am mistaken in that. If that be the case, this illustration that the speaker has given would indicate that the locomotive exerted over 2,000 indicated horse-power. It seems to me that is far in excess of the steam generating power of the boiler.

Mr. Soule.—In reference to that indication of 1,000 horse-power, I simply said that that would be the conclusion which we should be justified in arriving at if the number of notches in the integrator record line was the same as the number of notches in the time record line. Of course, if the locomotive was not capable of developing sufficient horse-power to correspond to 1,000 horse-power developed at the dynamometer spring, that condition never could exist. I was not aware before that the efficiency of the locomotive was reputed to be so very low as 42 per cent.; if that is true, it never could happen that the number of notches would be the same on the two lines, because the largest horse-power that I have ever heard attributed to a locomotive, so far, is 1,750.

Mr. Wm. O. Webber.—I have no recent data to substantiate

what I have to say, but I was the original engineer of tests of the Chicago, Burlington, and Quincy road, and made a large number of experiments, indicating locomotives and ascertaining the resistance of trains. My recollection is that we got efficiencies all the way from 62 to 78 per cent. on locomotives, but I have not any of the data now at hand in my possession.

The President.—I would ask Mr. Webber if he remembers what the maximum horse-power was at the cards.

Mr. Webber.—No, sir, I do not know. Those tests were made from 1876 to 1881 or 1882, and I have no recollection at all. The engines on which our tests were made were not large engines in those days. Most of our tests were made on 16 by 24 engine—16 and 17 by 24 engine. I think that the largest indicated horse-power we got was something like 1,000 to 1,100, not over that. But those were small engines.

*Mr. Max H. Wickhorst.**—In answering the questions asked in the discussion, I would say, first, in reply to Mr. Nagle, that I found, while getting up the integrator, it was very necessary to have the bearings for the steel wheel as nearly frictionless as possible, and finally used bearings consisting of a hardened steel pivot in a hardened steel cup. Probably agate cups would be better yet. Where bearings are not almost frictionless, the error from slippage might be serious. In the use of the instrument, I have so far used a hardened steel wheel on the brass disk which had shellacked on to it a piece of smooth enamelled cloth, giving a rubber-like surface. This, however, has seemed to me unnecessary, and I expect now to let the steel wheel rest directly on the brass disk.

The method which Mr. Soule suggests for obtaining the dynamometer horse-power is simple and valuable. I have not heretofore used the dynamometer diagram in this manner, and therefore wish to thank Mr. Soule for the method to which he calls attention.

* Author's closure, under the Rules.

No. 871.*

THE CONSTRUCTION OF CONTRACTS.

BY REGINALD PELHAM BOLTON, NEW YORK CITY.
(Member of the Society.)

THE provisions of contracts are matters which, to any body of men engaged in almost any pursuit of business, are of direct interest. I have frequently found that engineers are considerable sufferers from their engagement in contracts which, by their lack of proper provision, involved them in loss or misunderstanding. The technicality of the questions liable to arise, and the increasing tendency to combine various constructions under the same contract, have led me in my practice to make a study of the matter of disputable points, with a view to their exposition in my specification, so that all parties shall, previous to entering on a contract, have the probable elements of discord as far as possible discounted.

My own form of contract has been a simple agreement in which for a certain consideration the parties agree to perform the work as described, and further agree to adopt as a portion of their agreement the clauses referred to. I have, however, frequently been foiled in this, I believe, laudable effort by the adoption by owner or contractor of the so-called "Uniform Contract," in which a number of people seem to have great faith, on account of its adoption and recommendation for general use by the American Institute of Architects and the National Association of Builders. I have found this contract lacking in practice, for reasons which I think may be of sufficient interest to command the attention of the Society, especially as many engineers are brought under its provisions indirectly as sub-contractors to builders and others.

The form is as follows, those phrases to which I desire to draw attention being italicised:

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* Presented at the New York meeting, December, 1900, of the American Society of Mechanical Engineers, and forming part of Vol. XXII. of the *Transactions*.

THE UNIFORM CONTRACT.

FORM OF CONTRACT

ADOPTED AND RECOMMENDED FOR GENERAL USE
BY THE
AMERICAN INSTITUTE OF ARCHITECTS
AND THE
NATIONAL ASSOCIATION OF BUILDERS.

.....
Architects.

This Agreement, made the.....day of

.....in the year one thousand nine hundred.....

by and between.....

.....

..... party of the first part

(hereinafter designated the Contractor), and.....

.....

.....party of the second part

(hereinafter designated the Owner),

Witnesseth that the Contractor, in consideration of the fulfillment of the agreements herein made by the Owner, agrees with the said Owner, as follows:

ARTICLE I. The Contractor under the direction *and to the satisfaction of*

..... Architects,

acting for the purposes of this contract as agents of the said Owner, shall and will provide all the materials and perform all the work *mentioned* in the specifications and shown on the drawings prepared by the said Architects for the.....

.....

.....

which drawings and specifications are identified by the signatures of the parties hereto.

ART. II. The Architects shall furnish to the Contractor such further drawings or explanations as may be necessary to detail and illustrate the work to be done, and the Contractor shall conform to the same as part of this contract so far as they may be consistent with the original drawings and specifications referred to and identified, as provided in Art. I.

It is mutually understood and agreed that all *drawings and specifications are and remain the property of the Architects.*

ART. III. No alterations shall be made in the work shown or described by the drawings and specifications, except upon a written order of the Architects, and when so made, *the value of the work added or omitted shall be computed by*

the Architects, and the amount so ascertained shall be added to or deducted from the contract price. In the case of dissent from such award by either party hereto, the valuation of the work added or omitted shall be referred to *three* (3) *disinterested Arbitrators*, one to be appointed by each of the parties to this contract, and the third by the two thus chosen; the decision of any two of whom shall be final and binding, and each of the parties hereto shall pay one-half of the expenses of such reference.

ART. IV. The Contractor shall provide sufficient, safe and proper facilities at all times for the inspection of the work by the Architects or their authorized representatives. *He shall, within twenty-four hours* after receiving written notice from the Architects to that effect, *proceed to remove* from the grounds or buildings *all materials condemned* by them, whether worked or unworked, and to take down all portions of the work which the Architects shall by like written notice condemn as unsound or improper, or as in any way failing to conform to the drawings and specifications.

ART. V. Should the Contractor at any time refuse or neglect to supply a sufficiency of properly skilled workmen, or of materials of the proper quality, or fail in any respect to prosecute the work with promptness and diligence, or fail in the performance of any of the agreements herein contained, such refusal, neglect or failure being certified by the Architects, the Owner shall be at liberty, after.....days' written notice to the Contractor, to provide any such labor or materials, and to deduct the cost thereof from any money then due or thereafter to become due to the Contractor under this contract; and *if the Architects shall certify* that such refusal, neglect or failure is sufficient ground for such action, *the Owner shall also be at liberty to terminate the employment of the Contractor* for the said work and to enter upon the premises and take possession, for the purpose of completing the work comprehended under this contract, of all materials, tools and appliances thereon, and *to employ any other person or persons to finish the work*, and to provide the materials therefor; and in case of such discontinuance of the employment of the Contractor he shall not be entitled to receive any further payment under this contract until the said work shall be wholly finished, at which time, if the unpaid balance of the amount to be paid under this contract shall exceed the expense incurred by the Owner in finishing the work, such excess shall be paid by the Owner to the Contractor, but if such expense shall exceed such unpaid balance, the Contractor shall pay the difference to the Owner. *The expense incurred by the Owner as herein provided*, either for furnishing materials or for finishing the work, and any damage incurred through such default, *shall be audited and certified by the Architects*, whose certificate thereof shall be conclusive upon the parties.

ART. VI. The Contractor shall complete the several portions, and the whole of the work comprehended in this Agreement by and at the time or times hereinafter stated .....

.....

provided that.....

.....

ART. VII. *Should the Contractor be obstructed or delayed* in the prosecution or completion of his work *by the act, neglect, delay or default of* the Owner, or *the Architects*, or of any other contractor employed by the Owner upon the work, or

by any damage which may happen by fire, lightning, earthquake or cyclone, or by the abandonment of the work by the employees through no default of the Contractor, *then the time herein fixed* for the completion of the work *shall be extended* for a period equivalent to the time lost by reason of any or all of the causes aforesaid; but no such allowance shall be made unless a claim therefor is presented in writing to the Architects within twenty-four hours of the occurrence of such delay. The duration of *such extension shall be certified to by the Architects*, but appeal from their decision may be made to arbitration, as provided in Art. III. of this contract.

ART. VIII. The Owner agrees to provide all labor and materials not included in this contract in such manner as not to delay the material progress of the work, and in the event of failure so to do, thereby causing loss to the Contractor, agrees that he will reimburse the Contractor for such loss; and the Contractor agrees that if he shall delay the material progress of the work so as to cause any damage for which the Owner shall become liable (as above stated), then he shall make good to the Owner any such damage. *The amount of such loss or damage* to either party hereto *shall*, in every case, *be fixed and determined by the Architects* or by arbitration, as provided in Art. III. of this contract.

ART. IX. It is hereby mutually agreed between the parties hereto that the sum to be paid by the Owner to the Contractor for said work and materials shall

be $.....

.....

subject to additions and deductions as hereinbefore provided, and that such sum shall be paid in current funds by the Owner to the Contractor in installments, as follows:

.....

.....

The final payment shall be made within.....days after this contract is fulfilled.

All payments shall be made upon written *certificates of the Architects to the effect that such payments have become due.*

If at any time there shall be evidence of any lien or claim for which, if established, the Owner or the said premises might become liable, and which is chargeable to the Contractor, the Owner shall have the right to retain out of any payment then due or thereafter to become due an amount sufficient to completely indemnify him against such lien or claim. Should there prove to be any such claim after all payments are made, the Contractor shall refund to the Owner all moneys that the latter may be compelled to pay in discharging any lien on said premises made obligatory in consequence of the Contractor's default.

ART. X. It is further mutually agreed between the parties hereto that no certificate given or payment made under this contract, except *the final certificate* or final payment, shall be conclusive evidence of the performance of this contract, either wholly or in part, and that no payment shall be construed to be an acceptance of defective work or improper materials.

ART. XI. The Owner shall during the progress of the work maintain full insurance on said work, in his own name and in the name of the Contractor, against loss or damage by fire. The policies shall cover all work incorporated in

the building, and all materials for the same in or about the premises, and shall be made payable to the parties hereto, as their interest may appear.

.....

.....

ART. XII. The said parties for themselves, their heirs, executors, administrators and assigns, do hereby agree to the full performance of the covenants herein contained.

In Witness Whereof, the parties to these presents have hereunto set their hands and seals, the day and year first above written.

In presence of

..... SEAL

..... SEAL

..... SEAL

..... SEAL

In so far as this form of agreement may be utilized for the purposes of contracts of an engineering nature it is a very lame and amateur affair. It does not appear to have had that amount of technical and legal ability in its composition which a document of so much importance would properly demand, but it is evidently a rather feeble attempt to produce some sort of form which shall avoid the necessity for recurring to a lawyer when an agreement is to be entered upon. A little acquaintance with law, as well as a little technical knowledge of any sort, is proverbially a dangerous thing.

An agreement, to be satisfactory for general use, must manifestly be a very skeleton affair. In this instance it is in part unduly detailed for the purpose, and in other respects entirely wanting in proper provision. It is a good axiom that in such agreements the easiest way to avoid misunderstandings is to avoid terms liable to misunderstanding.

ARTICLE I.

The architects or engineers should not merely be named as acting as agents of the owner, but a specific delegation of authority to act on every question connected with the contract should be made binding on the owner. Absence of this provision enables

architects or engineers to assume or decline responsibility at their discretion.

"*Satisfaction*" is a loose term which has caused endless difficulties; and, as the courts have over and again decided that dissatisfaction must have a reasonable basis, the term might just as well be made clear by the addition of the words "proper" or "reasonable."

The word "*mentioned*" is also liable to misconstruction; and a better and more secure word is "described"—the object of a properly written specification being to so describe all the details that they can be identified by those familiar with the trade in question. Only too many architectural specifications are, however, drawn on a "mentioning" basis.

ARTICLE II.

I do not think the architects or engineers can in equity maintain a property in published copies of their drawings and specifications. They are necessary to the contractor, and are afforded as part of the agreement, and are a component of his defence against unjust claims or for recovery of his money.

This clause is a matter between the owner and the professional man.

No consideration passes between the contractor and the professional man, and therefore this provision is futile on the face.

ARTICLE III.

This clause lacks an important provision in the interest of the owner, viz., that any additional work or alteration of same shall be carried out in the same manner as the work actually comprised in the specification, and under the provisions of the agreement. There is no binding agreement on the part of the contractor to do any alteration work, even if a written order is issued, as he has only agreed to obey their directions in respect of the specified work. I do not see why the value of work added or omitted should be computed by the architect rather than by the contractor. The latter is in a far better position to ascertain the most dependable figure, having access to information as to labor, and a knowledge of the actual cost of materials and freight, which is not available to architects. As a matter of fact, in ninety-nine cases in a hundred the figures are so ascertained, and the architects use them as a basis for their alleged original findings. The saddle should set the other way round. The clumsy arbitra-

tion provision should be placed in a clause by itself. It does not exclusively appertain to the provisions of this article, but to Nos. VII. and VIII. Its proper position is as Art. XIII.

It would be much better drawn in manner usual elsewhere, so that an agreed or preliminary reference may be made to one disinterested party only. As it is, the expense of the services of three arbitrators is liable to preclude the operation of the provision.

ARTICLE IV.

The requirement that contractors shall commence removal of condemned material within twenty-four hours after receiving notice is, for very many cases, an impracticable one.

A mere notice from the architects of their condemnation does not necessarily prove that the work is justly condemned, and the contractor would be fully justified by the courts in taking any reasonable time to ascertain, by other inspection and opinion, by test or by the operation of time and of the elements, whether the work is not in fact in compliance or reasonably satisfactory. The time limit is, therefore, only an attempt at constructing a club to enforce an instant compliance with the demands of the architects, or, in default, to constitute a breach of covenant.

ARTICLE V.

If, by misfortune, by loss, or by the underestimating of the work, the contractor finds himself in the position provided for in this article, he has bound himself to stand by, without authority to interfere in the methods, prices or arrangements by which his contract work is completed by the owner.

I do not know if this matter has been fought out in the courts, but equitable law would appear to me to demand that a man should have a voice in the disposition of his own property, and that he should not be bound beforehand to the acceptance without the relief of arbitration, of the dicta of the architects, who are agents of the party disposing of the money.

The construction of the article assumes as a basis the injury only of the owner, and ignores the probability of injury of the contractor by the operations of the owner or his agents.

Numerous cases are known where contractors have been led into this position of forcible termination of their contract rights, by action, direct or indirect, of the owner or of his agents.

No remedy would, however, under the clause, be found for a

contractor who had been over-persuaded to accept a contract on terms which afterwards landed him in difficulties, or who had based calculations on insufficient information or plans, or who had declined to proceed with work insufficiently detailed, or to rebuild work so tardily condemned as to involve destruction of other work to a ruinous extent.

The wording of this article is a very good illustration of the spirit of such agreements as that under consideration, which regard the owners' contingent profits, and his rights in possession of the monetary equivalent of the work, as superior to any of the parallel rights of the contractor.

When the proper view of the respective rights obtains, it will be realized in law that as soon as a contractor is pledged by an owner to the commission of certain duties, the setting in operation of his organization, and the undertaking of immediate and prospective expenditures, all involving inevitable cost, then the owner is by the same operation pledged to the issuance of the monetary equivalent for the same, and will not be permitted to dispose of that equivalent, which has become in equity the property, in escrow, of the contractor. The equitable view and system is that a contract constitutes a lien or engagement by the owner of his belongings, to the extent of the sum involved, and to prevent fraudulent disposition of the amount, it would be only fair that it should be deposited with suitable authority for its due disposition, either in payment of the contractor, or in his default, in payment for the means to complete his work.

For this proper system to obtain, however, the general body of business men must be considerably educated from their present standpoint, and new methods of insurance of payments will probably then be brought to the aid of proprietors of money.

The present system bears a good deal of the methods of savage rights of possession.

ARTICLE VI.

Is a skeleton, and may, therefore, be made to comprise a number of desirable features, which might have been provided, and which I outline later.

ARTICLE VII.

In this article the architects, or engineers, are constituted the judges of the value and extent of their own acts, neglect, delay, or default, and the injustice is further complicated by another

provision of a time limit of similar impracticable nature to that in Article IV.

Such an article cannot be good in law, and the only saving clause is the reference over the heads of owner and agents to arbitration, a very clumsy method of balancing a manifest impropriety.

ARTICLE VIII.

The same remarks hold good in respect of Article VIII., which is almost equally one-sided.

I venture to doubt if a man can thus sign away his right to justice, or place judgment for the losses he sustains by the action of another, in that person's entire discretion.

ARTICLE IX.

If certificates by an architect or engineer are unduly or unreasonably delayed, there should be some penalty of interest added—a spur to action in the direction of payments is just as proper as the same provisos appertaining to the contractor.

Liens are very carefully safe-guarded in the owners' interest, but ignored from the point of view of the contractor, who has as much right to just protection of his property.

ARTICLE X.

Is so drawn that the "final certificate" constitutes conclusive evidence of full performance of contract, but no definition is given of what this final certificate is, and it is open to the construction that it is that issued after the work is completed in the sense of the contractor.

The above criticisms deal only in a negative form with the "uniform contract," and lead one to wonder at this result of the united efforts of two important institutions.

For the purpose of filling the gaps which are dealt with above, and others required by suitable care for details, I suggest provisos covering the following requirements in a proper construction contract, and especially of one dealing with engineering materials in any form:

It is not enough that these provisions should form part of the specifications, as they require the evidence of consideration for performance, where they involve expenditure of any kind by the contractor.

1. Compliance with laws and regulations by contractor, and indemnification of owner by him for breach or violation by himself or by those employed by him.

2. Payment of fees, for permits and inspections, by contractor.

3. Liability for materials stored on premises of owner. It is usual for owner to be exempted from all liability.

4. Employment of certain classes of labor such as union labor.

It is very common to find an owner endorsing and assisting, by influence and "comfort," his contractor, in resisting the employment of union labor, without realizing that the contractor is securing additional profit in the case of successful resistance.

It is fair to assume that no cautious contractor in these days, when making a bid upon work of any form of construction entering into a building, fails to take into account the value of union labor. In certain cases he does more, by estimating the amount of work to be expected from each workman and helper, and deciding thereupon the time element as well as cost.

If his bid is accepted, the owner has therefore engaged a title to the employment of labor of that value, and, if so understood at the time of the acceptance of the proposal, any refusal to employ that labor can only properly be made with consent of the owner, and any loss of time on the work due to resultant strikes, or any diminution of the cost of labor, is taken directly from the owner's pocket.

These remarks bear especially upon the form of action which the workingmen's unions have recently adopted to enforce adoption of union labor in all branches of a trade.

The owner is entitled to an understanding on this matter as part of the consideration involved in his contract. If he desires to avoid the possibility of costly delay in delivery of his purchase, and is willing to pay therefor the price which includes the employment of union or any other special form of labor, he is entitled to the discharge of the obligation.

If he engages the services of a contractor who employs non-union labor, he is entitled to be made aware beforehand of the fact and thereby to face the risk attendant on possible agitation, just as much as he is entitled to know that this contractor will employ skilled workmanship of a certain order.

If, being aware of the fact, he does not agree with his contractor that the price he pays for his work is contingently inclusive of

a necessary employment of union or other special labor, then he, or his agent, is lacking in proper prevision in a matter of very common occurrence.

If a demand be made, however, upon a contractor employing union labor for an increase in the rate of wages current at the time of the acceptance of the contract, the contractor is entitled to the sympathy and aid of the owner, and should be entitled to require it and to be free from any penalty as regards consequent delay in construction, or any holding back of payment on partly completed work.

In this matter it has always seemed to me that an agreement could readily be reached by reasonable and fair-minded representatives of the employing element and of the employed.

I do not believe that the unions would refuse to make their members serve to the completion of a construction undertaken by the contractor in good faith, depending upon the continuance of the current rate. The authorized representatives of the employed could, without loss of dignity by contractors, be notified of the acceptance of a contract and its inclusion of the price of his estimated labor at the current rate.

If, thereafter, a general increase of wages in the trade involved should be demanded, it should not equitably and need not in practice come upon the contractor, but should be made to the owner, who then assumes directly a decision which is properly his own.

These remarks cover equally the case of the employment by a contractor of non-union made goods, the use of which can be, and should equally properly be, understood to form part of the consideration paid, or to constitute a risk assumed by the party profiting thereby.

5. In all composite constructions some distinct provision is desirable as to non-interference with the work of other contractors, and in many cases as to positive and active coöperation with another contractor; and in addition, accidents and damage caused by one set of workmen to another set or to their work require to be considered.

6. The contractor for a construction is usually required to provide a guarantee against defective workmanship or material, and sometimes a guarantee of working economies.

His own protection should require the guarantees of his subcontractors, or of the actual manufacturers of the articles he sup-

plies, to be, in some cases, substituted. It is by no means uncommon to find that a guarantee of a machine is given by a small builder or erecting engineer, whose credit is so small that the guarantee is of little positive value, while the apparatus should have been guaranteed by the powerful and substantial firm who made and perhaps actually installed it.

7. Similarly, a guarantee and indemnification should nowadays be taken covering the use of patented appliances and methods, but such indemnification should be released by the guarantee of the actual patentees. In the case of disputed and undecided patents this direct indemnification should be secured by bond. These provisions are equally necessary in the interests of both parties to the contract.

These suggestions are not to be regarded as comprehensive of the subject, but they are designed to lead up to the preparation of a more equitable and suitable form of contract than is now commonly available. But when the best form of skeleton contract has been devised, it will still remain a better course for the cautious man of business to employ expert ability for the avoidance of misunderstanding and provision for technical eventualities. But the preparation of contracts for constructions involving technical knowledge is not successfully to be intrusted to exclusively legal talent.

DISCUSSION.

*Mr. B. M. Wagner.**—No one general form of contract can be made to fit all cases. Even the best form that can be devised will be fit for only a few cases.

The single form of agreement, as suggested by the author, where each of the parties agrees to do certain things in consideration of specified performance on the part of the other, would seem best.

Each and every contract calls for special conditions. Some of these conditions may be common to a greater or smaller number of contracts, as the case may be. Such clauses are mostly of a legal or semi-legal nature, and should be formulated by a joint committee of engineers and lawyers.

As regards the merits or lack of same in the contract discussed by the paper, my opinion is as follows:

* Assistant Engineer, Department of Water Supply, Brooklyn, N. Y. By invitation.

I. The parties are not defined very clearly, and the powers of the engineers are very obscure. The engineer should be named as the final judge of the fitness and correctness of all work performed and materials furnished. The following expresses my ideas on the subject:

To prevent all disputes and litigation, it is further agreed by and between the parties to this contract that the engineer shall in all cases determine the amount or the quantity, quality, acceptability, and fitness of the several kinds of work which are to be paid for under this contract, and he shall determine all questions in relation to said work and the construction thereof, and he shall in all cases decide every question which may arise relative to the execution of this contract on the part of the said contractor or of the owner, and his estimate and decision shall be final and conclusive upon said contractor and upon the owner; such estimate and decision, in case any question shall arise, shall be a condition precedent to the right of the party of the second part to receive any money under this agreement.

II. Would not be upheld in any court.

III. As regards additional work or alterations, where itemized prices are given per unit of work, such prices should be made to include all additional work. Where a lump sum is named, the following clause would seem to be just, and a fair provision for the interests of both parties.

For all extra work and not herein specified, its actual reasonable cost to the contractors, plus fifteen (15) per cent. of said cost.

IV. Must take issue with the paper on this subject. Some one must be the judge of the fitness of materials used, and the position of the engineer would seem to me to be that of arbiter as between owner and contractor. Though paid by the one party, any injustice towards the other would react to the injury of his professional reputation, and mean a loss greater than a mere financial one.

V. As the parties to the contract are so of their own free will, the losses that either party may sustain by respective reduction or increase in the prices of materials are mere understood business risks, covered in the case of the contractor by his margin of profit.

Losses by the contractor due to acts of the owner or his agents could probably be made good by legal action.

VII. If the contractor under his seal has accepted the engineer as the final resort, he should be kept to his agreement. Fairness and justice would seem to demand that the owner be likewise bound to accept his engineer's decisions. Outside arbitration is cumbersome, costly, and generally unsatisfactory.

VIII. What is said in regard to VII. holds good for this article.

IX. The time and every other circumstance of making certifications and payments should be clearly stated, and the contractor would then be in a position to seek redress through the courts in case of any delay or evasion in the matter of making payments.

X. As regards final certificate, it should be described as final and conclusive alike for the owner and the contractor. The following clause is one often used, but it is not all it should be :

It is further expressly understood and agreed by and between the parties hereto, that the action of the engineer, by which the said contractor is to be bound and concluded according to the terms of this contract, shall be that evidenced by his final certificate, all prior partial payments being made merely upon estimates subject to the correction of such final certificate.

As to the points brought out in the paper :

No. I. Seems just.

No. II. Seems just.

No. III. Seems just.

No. IV. It seems to me that to specify union labor would be outside of one's rights. The result desired could be obtained by a clause calling for skilled labor in the different classes of work called for, and requiring the contractor so to conduct his work as not to interfere with or needlessly delay other contractors. This if accompanied by a penalty disguised as liquidated damages for delay will generally bring about the desired results. It would not be right to make the owner suffer for the contractor's private troubles with his workmen.

In the matter of guarantee of patented articles, the seller should give proof of his right to the use of same, and as for a guarantee of an entire plant, a retained percentage for a certain period of time has been found effective.

Mr. F. A. Scheffler.—This is a very interesting and important paper. All of us who have been subject to the mercy of architects using the form of contract which Mr. Bolton reproduces

have, I warrant you, at times almost regretted having accepted such undertaking. I doubt very much whether discussion before a body of mechanical engineers will ever result in a modification of this "uniform contract"; but that it ought to be modified, and the contractor shown all the consideration he is entitled to, is an undoubted fact. Publicity herewith given is one of the best things towards accomplishing the required changes.

I am glad to note Mr. Bolton favors inserting a clause relative to employing union labor in his and all contracts or specifications. If this is done, and a contractor accepts the work under such provisions, no one is to blame but himself if he is troubled with walking delegates who insist that he employ men in their respective associations; otherwise they will strike, and call out all trades employed on the building.

This, of course, only applies to cities like New York and others where the trade-unions are affiliated.

Mr. Edward A. Darling.—I think Mr. Bolton has made out a good case, but it would seem that he has brought it before the wrong court. The American Institute of Architects is responsible for this omnibus contract, and I would suggest that theirs is the proper arena in which to throw down his gauntlet. Any attempt on the part of laymen, or even committees of laymen, to draw up legal documents smacks of "Every man his own doctor," and brings fish to the lawyer's nets sooner or later. Some of these "contract forms" that I have seen remind me of the first fire-insurance policy I ever read through, that left me wondering whether there were any conditions whatever under which the company would pay the poor creature they insured.

Some years ago I had occasion to take the matter of contracts up with one of the foremost authorities in this country on the law of contracts, and he told me that "safety lay in simplicity." A simple agreement by one party to perform certain works for another party for a consideration, with a statement that the works are to be done in accordance with plans and specifications which are to be identified, and form a part of the agreement—this is a safe instrument. A written acceptance by one party of a proposal by another also constitutes a complete contract.

All contracts must be based on simple equity between man and man, to stand in a court of justice; and when an architect or engineer seeks to enmesh a contractor in a voluminous and ambiguously worded contract, he must know, or should

know, that the victim cannot even *sign* away his rights before the law.

In all undertakings involving considerable sums of money, the safest way is for the owner to have a contract prepared by a competent attorney, basing the contract on a memorandum of conditions submitted by the architect or engineer. The proposed contract should then be submitted by the contractor to his attorney before receiving his signature.

We all begrudge lawyers' fees, but the ounce of prevention is cheaper than the pound of cure. As to the particular "form" of which Mr. Bolton complains, I think his points are well taken, from an engineer's standpoint; as a layman, I would not pretend to discuss their legal soundness. The question of union labor is the particular *bête noir* that vexes owners, architects, and engineers more in New York than anywhere else in this country, and I consider Mr. Bolton's suggestion of making the labor unions at least a tacit party to every building contract a valuable one.

Mr. William H. Bryan.—The proper interpretation of contracts is a matter of decided interest to the engineer. In many forms of construction he is often given the position usually occupied by the architect on buildings. On installations embodying both building and engineering construction he is often associated with the architect and given duties and responsibilities of equal importance. This subject has occupied my attention for some years, and was discussed before this Society in my paper on "The Relations between the Purchaser, Engineer, and Manufacturer," read at the Niagara Falls meeting. See *Proceedings*, vol. xix., p. 686.

In the main I agree with Mr. Bolton, but there are some parts of his recommendations in which I cannot fully concur. His discussion is principally from the standpoint of the contractor—rather an unusual position for the engineer, who generally represents the owner. In the latter situation it can readily be seen that the view-point might be quite different, even though the question is approached with equal fairness. I have found that, as a rule, the contractor is quite able to take care of himself, and that it is the owner whose rights need to be guarded. This view has been forced upon me by the unfair and one-sided printed forms of contracts which are often submitted by large manufacturers and contractors. They protect the seller

in every possible way, but, as a rule, leave the purchaser very few rights. This has made it necessary for me to prepare my own form of contract, which is the result of an exhaustive study of all the different forms which have come under my observation. It is quite different from the "uniform contract" which Mr. Bolton discusses, and which I have never used, finding it wholly inadequate to my purpose. My contracts and specifications are divided into two general or principal heads—"General Provisions," and "Specifications in Detail." The latter must, of course, always be adapted to the work, and I find that it is almost always necessary to revise the former as well, to suit special peculiarities of each case.

My specifications have sometimes been criticised as being unnecessarily rigid, but I have rarely found it necessary to enforce them literally. They are intended principally to control incompetent or dishonest contractors. Where the contractor is proceeding with his work intelligently and in good faith, he is always dealt with liberally, and even leniently.

Taking up, now, some of Mr. Bolton's criticisms of the "uniform contract," there should certainly be a clear and distinct definition of the duties, powers, and responsibilities of the architect or engineer, independent of, or acting in conjunction with, the owner.

The ownership of drawings has long been a mooted subject. My practice is to give the owner and contractor a complete set each, and permit them to retain them. Architects continue to assert exclusive ownership in drawings, but I believe that this contention has, as a rule, been denied by the courts.

As to changes and extras, my practice is to insert clear and definite clauses giving the engineer the right to order changes and to determine their value. The right to order changes carries with it the right to direct how the changes shall be conducted. It is necessary that he should decide as to the cost of changes or extras, in order to protect the owner from extortion. It is, unfortunately, a not uncommon practice for a contractor to take the original work at about cost, relying for profit upon the probability of extras, on which he can make excessive charges, as no competition can be had. When time permits, I ask the contractor to submit his estimate on the value of the changes in advance. When this is impossible, I ask him to submit his estimate after the work is finished. This I check

over by other quotations. The contractor's charge, however, is only allowed in full when found to be reasonable.

A special paragraph in my specifications makes the engineer the judge of all disputed points which may arise. Either party, however, is given the right to appeal to arbitration, and this, I think, is entirely fair to all parties. There must be some means of getting a prompt decision on disputed points, either party having a remedy in arbitration if he feels aggrieved. In such cases the architect or engineer must use the utmost fairness. If his decisions favor either the owner or contractor, he will soon lose his reputation for impartiality. The contractor, as well as the owner, should feel that his interests are safe in the engineer's hands. The architect or engineer often finds it necessary to decide a disputed point against the owner who employs and pays him. It is just as much his duty to protect the contractor against unreasonable demands on the part of the owner as it is to see that the owner gets everything he is entitled to. It is not an uncommon experience to find the equities somewhere between the claims of the two, in which event the engineer's decision is quite as likely to offend both parties as to please them.

I agree with Mr. Bolton's suggestion that one arbitrator would be an improvement over three. The expense, delay, and complications which attend arbitration by three men frequently render it impracticable, and even when resorted to, the third man must usually make the decision.

Condemned material should be removed promptly, to prevent its use elsewhere on the work. I see no objection to limiting the time, as the contractor has his right of appeal. In the event of the work being taken out of his hands and finished by the owner, his right of appeal should protect him from unnecessary loss.

I think it would be unwise to expect the owner to deposit the contract sum in escrow, as Mr. Bolton suggests. If the contractor has any doubts of the owner's fairness and financial responsibility, he is justified in taking proper steps to protect himself by bond or otherwise. I see no objection to the architect's duties under articles VII. and VIII., subject to appeal, as above.

The certificate for final payment in my work is not evidence of complete performance of contract. It is customary for builders

of mechanical and electrical apparatus to guarantee their work for one year. In such cases my specifications provide that the contractor shall make good any defects which may develop, which, in the opinion of the engineer, are due to defects in original material, workmanship, or design. I have found this a most excellent clause for the complete protection of the purchaser.

My specifications usually cover the first three of the four provisos suggested by Mr. Bolton. As a rule, I do not require the contractor to use union labor, but the specifications provide that he must provide first-class workmen, work in harmony with all other workmen on the job, and complete the work by a specified time. I have usually found these provisions sufficient to prevent delays by labor troubles.

I cannot agree with Mr. Bolton that the owner should reimburse the contractor in case wages have advanced, unless the owner has delayed the work unreasonably. It is reasonable to presume that the contractor has either protected himself by contracts or agreements, or that his margin is sufficient to cover ordinary fluctuations.

I require protection against claimed infringement of patent rights, but should consider it impracticable to go to the extent of requiring releases from actual patentees on all the details of large installation.

An important point which often troubles engineers and architects is not discussed at all by Mr. Bolton; namely, whether or not a forfeiture should be exacted in the event of failure to complete the work by the date specified. It has been claimed that no forfeiture can be exacted unless a bonus is also allowed in consideration of completion earlier than the contract date. This, however, is unfair, as the situation is frequently such that, while the owner will suffer by failure to complete, he cannot profit by earlier completion, for various reasons. Other contractors, whose work is equally essential to the plant, may not be ready, and, even if they were, it sometimes happens that the plant cannot go into service earlier, as in the case of the lease of the building or a city lighting contract beginning on a certain date. It is true that there have been court decisions denying forfeiture when no bonus was promised, and it is also true that the courts will not uphold an unreasonable or excessive forfeiture. It is equally true, however, that when the actual

damage is difficult to determine, the two parties to the contract may agree upon what shall be the measure of damage in case of delay, and the courts will uphold such an agreement.

While it is rare that a contract form covering the general provisions can be used in its entirety, it would seem possible for a much better form to be devised than the present "uniform contract," and it might be well, therefore, to revise this document in the light of later experience. I take the liberty of suggesting, therefore, that steps be taken at this meeting looking to the appointment of a conference committee composed of members of the American Institute of Architects, the National Association of Builders, and the American Society of Mechanical Engineers.

Mr. George I. Rockwood.—It so happens that all the papers of this meeting, with one or two exceptions, deal with subjects in which only a few of us are directly interested, and as I am one of that number, that is my excuse for speaking so frequently. But I must express my approval of Mr. Bolton's paper and of his attitude, and refer to the arrogance, not to say impudence, of architects in general and engineers in general, in their relations with contractors. I hardly think that Mr. Bryan understands Mr. Bolton's paper when he says that Mr. Bolton looks at the subject from the standpoint of the contractor. It appears to me that he looks at it from the standpoint of equity, from the standpoint of justice; that his views are just and in the interest of both parties, therefore tending to a quick settlement of the contract. The ordinary architect's contract is nothing less than a piece of impudence, looked at from the standpoint of the contractor. The average contractor has to adopt, to protect himself, a servile and cringing attitude which he is very far from really feeling, and it is time that the contractor was elevated to a position on an equal plane with that of the architect. It seems to me, Mr. Bolton's paper is especially timely; that it appears at the "psychological moment" when the attitude of the engineer toward the contractor ought to be reconsidered.

Mr. J. Leland Wells.—I would like to say a word on this subject from a contractor's standpoint. I am personally obliged to Mr. Bolton for taking the matter up, because contractors have a good deal to suffer from under existing contracts, under contracts as they are written, and if Mr. Bolton or any other gentleman in this room would go still further and get up a contract which

would insure the contractor that he would always get his money if he got his work done, it would be ever so much better.

There is, however, criticism to be offered from my point of view, because Mr. Bolton's proposed contract is too long and it says too much. It is impossible to cover in a written document, or otherwise, every contingency that may arise; and when you undertake to cover a good many points, you are surely apt to leave out some. As, for instance, I let a house once to a tenant, and I thought I was doing a very smart thing when I provided that he should fix the plumbing if it was frozen, and that was put in the lease. The result was that he fixed the plumbing when it was frozen, but, in consequence of that, I had to fix every other blessed thing about the house, and about seventeen times during each month of tenancy. The contract says too much. The contract should be simple. One discussion read indicates to my mind just what it should be. It need not occupy more than a page.

Other criticism I would make is as to the clause in relation to the contractor guaranteeing patent infringements; and I can tell you, gentlemen, that that is not worth the paper it is written on. Put it in the contract as much as you like; I will sign those contracts every day, and the guarantee is not worth a two-cent piece, and for this reason: that in doing so I am simply the agent of the man who directs me to put in a specified thing. He has no right to do it. It is unjust, but it may be put in, and they think they secure themselves; but, as a matter of fact, it does not secure them at all.

The next point is the question of union labor. No contractor in New York with any kind of sense will employ anything else, and there are not any mechanics outside of union labor here who are worth a cent. But if you put that question of union labor in a contract and ask a contractor to sign it, you are simply putting a club in the hands of his employees to do what they like with him, for no good at all—not a bit. Union labor is there just the same; but if there is an underground railroad in your shop—there is one in mine, and my employees know when I get a contract before I do, many times—and if that clause becomes known, they will say: "We have got Wells this time. That is worth four and a half a day on this job, because he has got to employ union labor."

I happen just now to be in the throes of one of our periodical

union mix-ups. It is not a question of employing union labor. It is simply, in my opinion, a question of various organizations in the same trade wanting to elect various walking delegates; and as long as the personal ambition of the walking delegates exists, just so long will these two branches of one particular union have amusement with myself and fellow contractors in the same line of business. If I were to sign a contract which said union labor, which one of these unions would I take? In this particular case in question I simply sit still and do not take one side or the other. My business, I hope, will go on just the same. But I would rather have my contracts as free from clubs of any kind on the part of architects, engineers, and other people who are looking after my work as I can make them.

*Mr. Reginald P. Bolton.**—I would only like to say that I think the general opinion expressed seems to justify me in my own idea, as expressed in my paper, that the best form of contract is simply an agreement to perform certain duties for certain money, under conditions stated in the specification, and therefore previously understood by the parties when they are bidding upon the work, which procedure is, I am confident, the proper way. Forewarned is forearmed.

My general contention may be summed up in this manner. Unless the conditions of a proposed contract are before a contractor at the time of his bidding, he cannot be held to them as part of his bargain.

His bid is made on what he sees and has before him, that is, whatever is contained in plans and specifications. As soon as his proposal in respect of those is accepted, the contract exists. The contractor is then under no obligation to sign any further contract, certainly not one the conditions of which may affect the bargain already struck.

If any condition of such a contract conflicts with the specification or plan, or adds to or reduces the cost of executing the work, it can be of no effect, because there is no consideration for it, the named consideration being that agreed upon as the value of work comprised in the specification and plans unmodified by any conditions. It follows, therefore, that any specification should exhibit on its face all the conditions that will be required as part of the contract. If a "uniform" form is to be

* Author's closure, under the Rules.

used, it should be so stated in the specification, and the contractor then bids with that fact in view.

My point of view in this matter may appear to be more on the side of the contractor than of the owner. If so, it is because the owner's side has been the customary standpoint, and fairness demands that both sides of a question should be examined.

The owner occupies in these matters the intrenched position, possession of the value of the work done and knowledge of the requirements. The architect is his servant, committed to his interests, and urged by the powerful incentive of professional pride to insist upon the completeness and sufficiency and readiness of his preparations for the work; in other words, of his plans and specifications. He is nevertheless made the arbiter of these very questions, and the key to the contractor's remuneration is placed in his hands as a weapon. The system is liable, and is indeed subject, to constant abuse. The two parties to a bargain are on an equal footing. The agent of the one should count for no more than the agent of the other: both are simply delegates. All disputable matters can only be in fairness committed to a party who is the servant no less of the one than of the other; in other words, there should be a referee employed by both, who would be able to pass upon the acts or negligences of both parties, and also of their agents.

No. 872.*

APPARATUS FOR DYNAMICALLY TESTING STEAM-ENGINE INDICATORS.

BY CARLETON A. READ, DURHAM, N. H.
(Member of the Society.)

THE form of apparatus about to be described has been in use by the writer for about three years. It is an outgrowth of the old form of appliance for testing indicators—turning the steam on and off several times, and then, with the steam on, drawing a line on the card, and at the same time observing the pressure. To facilitate this work a three-way cock was used. From this it was but a short step to put a crank on the back-end of the cock and attach the indicator cord to it, thus working the indicator and cock at the same time. The device is also an outgrowth of one described by the writer's friends, Professors Peabody and Miller, in a paper read before the Society of Naval Architects and Marine Engineers in November, 1894. To Professor Miller and Mr. Albert F. Hall he is indebted for valuable suggestions.

Fig. 22 is a photograph of the apparatus as at present used in the engineering laboratory of the New Hampshire College, at Durham, N. H. Fig. 23 is a drawing to illustrate the general arrangement of the apparatus. As will be seen from the figures and description, all parts are standard articles, thus avoiding special patterns and castings. This apparatus was constructed by Mr. H. P. Andrews of the class of 1900, New Hampshire College.

K' and K are cylinders of 4-inch pipe, 3 feet long, capped at the ends.

A is an oil cup for lubricating the cock.

B' and B are test gauges.

C' and C are tees.

D is the indicator to be tested.

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* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

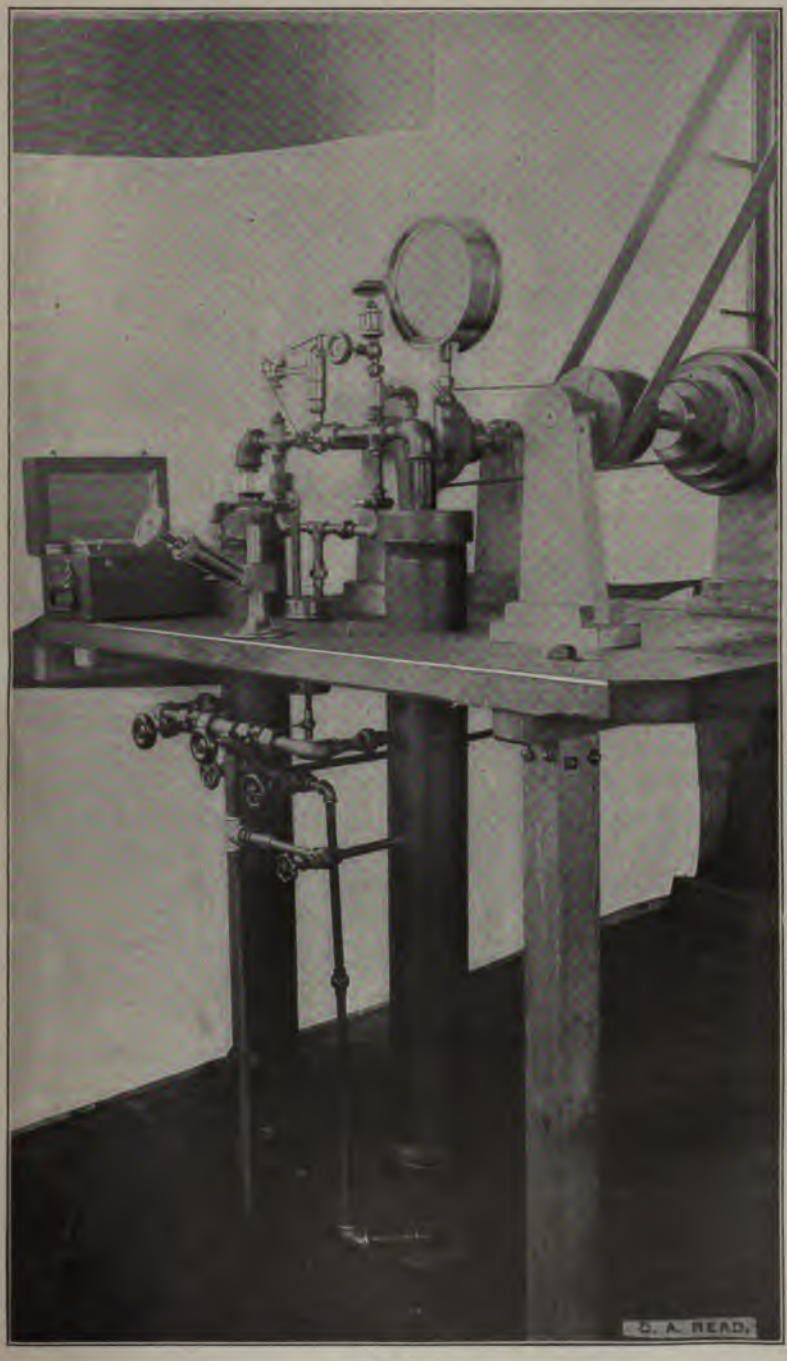

FIG. 22.

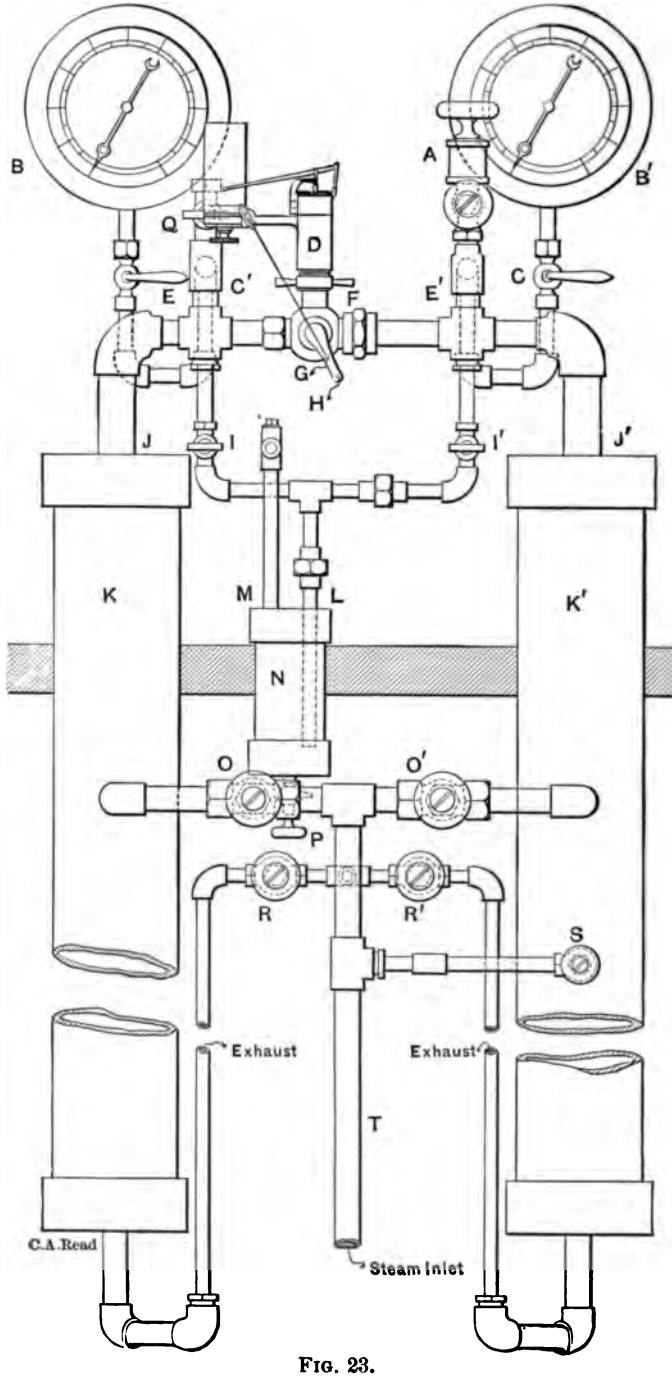
B
A
B'
Q
D
E
C'
F
E'
C
G
H
J
I
I'
J'
K
M
L
K'
N
O
O'
P
R
R'
S
Exhaust
Exhaust
T
C.A.Read
Steam Inlet

FIG. 23.

E' and E are crosses.

F is a three-way cock.

G and H are holes in which to insert pins for attaching the indicator cord.

I' and I are cocks for connecting the gauge-tester with K' or K.

J' and J are pipes connecting the cock and tester with K' and K.

N is an oil reservoir to prevent the steam and water from entering the gauge-tester.

L is the inlet to reservoir.

M is a portion of the connection between N and the (Crosby) gauge-tester.

P is a drain-cock for N.

Q is a cock to be opened when atmospheric pressure is desired in K.

O' and O are valves for admitting steam to K' and K. These valves are so-called needle valves, having very fine holes to permit delicate regulation of pressure.

S is a valve with larger opening than O' and O, for convenience in quickly raising the pressure in K'.

R' and R are valves for relieving the pressure in K' and K.

The three-way cock now used is the new pattern made by the Crosby Steam Gauge and Valve Company, and is but little changed for this work, couplings being used for attaching indicators of other makers. A larger cock is being constructed, arranged for indicators of any make. This will make the connections a little longer, but will be more like the connections of practice. A pulley is attached to the cock in place of the ordinary handle, and a crank to the opposite end for attaching a cord to actuate the indicator drum when operating the cock. The arm to which the cord is attached is clamped between the nut and washer of the cock. As ordinarily made, this would draw the plug too hard upon its seat. To obviate this difficulty, a carefully fitted washer is inserted between the outer washer and the end of the plug; the arm is then clamped between the nut and outer washer, the outer washer bearing against the inner, and this, in turn, against the plug. As the plug wears it is reground, and the inner washer ground a corresponding amount. By means of the stepped pulleys, shown in Fig. 22, the speed may be varied from 15 to 150 revolutions per minute.

When the indicator to be tested is to be used on a simple non-condensing engine, the valve O remains closed, and the cock Q is opened. Connect the indicator as shown in Figs. 22 and 23. Open the valve O' until the pressure in K' is about 5 pounds, and then shift the belt to the tight pulley. Revolve the weights of the gauge-tester, and regulate the pressure until it just balances these weights. Then press the pencil against the paper and draw the diagram. This operation is to be repeated for the desired intervals of pressure. After the diagram is taken, shift the belt to the loose pulley, open the cock to the atmosphere, and draw the atmospheric line. The similarity of the diagrams taken to those from an engine can be seen by reference to Fig. 24. When the indicator is to be used on multiple-expansion engines, close valve Q and proceed as before, maintaining the pressure in K approximately equal to the back pressure in the cylinder with which the indicator is to be used. When the indicator is to be used in connection with a cylinder where the pressure is at times below the atmosphere, a connection is made from Q to a condenser or ejector, and the pressure registered by a U tube.

Testing between the higher and lower or back pressure lines may be done in either of two ways:

First, follow the method already described, with the gauge-tester open to K' and the pressure in K approximately equal to the desired back pressure, and then with the gauge-tester open to K and the pressure in K' approximately equal to the desired steam pressure. If this is done on the same card, it gives both measured steam and measured back pressures. This is illustrated by Fig. 28. The diagram a represents the first movement, and b the second. With the diagram a the upper line is the one measured, and with diagram b the lower.

The second method is to attach a second oil reservoir and gauge-tester to K, and regulate both pressures at the same time.

Of course, with this apparatus it must be assumed that the pressure on the indicator while the cock is open to K' or K is the same as that in those cylinders. One check on the above is that the steam, back pressure, and atmospheric lines are parallel. After the indicator is filled with steam, the only flow is that necessary to make up for the leakage. That there is time for the pressure in the indicator to reach the desired pres-

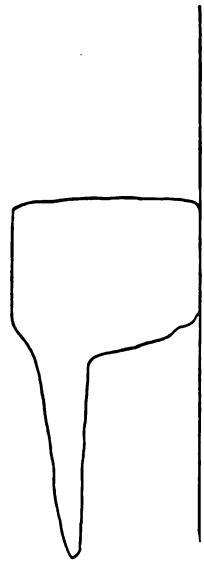

FIG. 25.

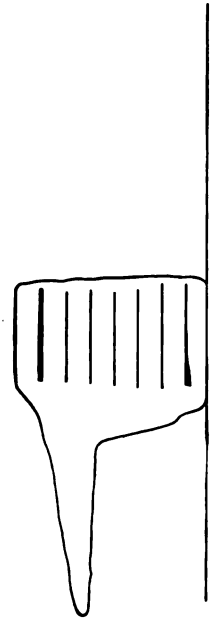

FIG. 26.

FIG. 27.

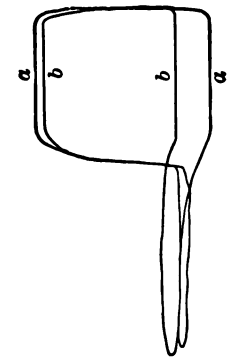

FIG. 28.

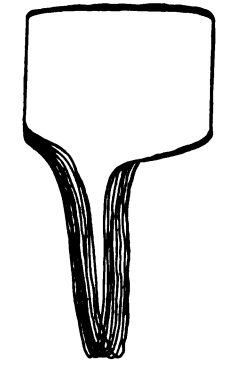

FIG. 24.

sure—at least when testing at 15 revolutions per minute—will be seen when it is realized that the indicator is in communication with K' and K nearly a second.

The question of pencil friction of course enters into the problem, but this is reduced to a minimum by the use of paper covered with a metallic preparation, and very fine metallic points. To entirely eliminate this error due to pencil friction with indicators which are electrically operated, sectors are to be attached to the cock to rotate with it, and the electrical connection made through these and a brush, which shall be in contact only while the horizontal lines are being traced. By this device the point is not in contact with the paper until it has reached its highest position, and not again until it has reached its lowest position.

A portable apparatus may be made by slight alterations of the present construction, the only difficult part to transport being the gauge-tester. There are few places where tests are made which cannot furnish a cylinder to take the place of K'. The gauge-tester and cock are then attached, and the cock rotated by hand. If there is a boiler in which the pressure may be varied, the connection can be made directly to that.

In Fig. 24 the pencil was pressed against the paper during 50 revolutions, showing that the pressure can be maintained constant.

In Fig. 25 the pencil was not constantly pressed against the paper, but was released an instant several times during the 6 revolutions that it represents.

The horizontal lines of Fig. 26 represent 5-pound intervals by the gauge-tester when the pressure in K' was the measured pressure and that of K atmospheric. Fig. 27 gives the same intervals of pressure in K and that of K' nearly constant at the higher pressure. In Fig. 26 it is the steam line and in Fig. 27 the back pressure line which is measured. With this apparatus the question of temperature of the spring, the sluggishness due to the ordinary methods, as well as all personal errors, except those due to balancing the weights, are eliminated. With a standard-speed, indicators and springs may easily and quickly be compared. If it is necessary to test several indicators at once, the cylinders K' and K may be horizontal and have several cocks connected with them.

DISCUSSION.

Prof. D. S. Jacobus.—I see no objection to the general method proposed by Professor Read for testing indicators; in fact, it is a very good method; but there are certain things which should be guarded against in testing indicators in the way described. In the first place, tests should be made at all the pressures at which the indicator is to be calibrated, to make certain that there is no undue friction. The friction in an indicator cannot be allowed for, because it acts first in one way and then in another, and is a variable element depending on the speeding of the moving parts and the particular form of the diagram which is taken. All we can do is to make sure that the friction does not exceed some amount which has been found to be the maximum allowable. With an indicator in proper adjustment, some special experiments which I have made show that the effect of friction is so small that it may be neglected.

Let us consider the details of the apparatus proposed by Professor Read. In the first place, in testing an indicator at pressures above the atmosphere, the steam should not act on it continuously, otherwise the spring will be heated above the normal working temperature. If a thermometer is placed above the piston of an indicator, and in the space occupied by the spring, the temperature registered will soon rise above 212 degrees Fahr., if the steam is allowed to act continuously on the indicator, because the steam which leaks by the piston will become superheated in the same way as that which passes through the orifice of a throttling calorimeter. On the other hand, if we make a similar measurement of temperature, with the indicator placed on an engine where it is used in obtaining diagrams, we will find no superheating. It therefore appears that in testing an indicator the spring should be maintained at a temperature of about 212 degrees Fahr. In the test we must, therefore, work quickly enough to prevent any superheating in the steam which escapes through leakage. It appears to me that the cylindrical reservoirs used in Professor Read's apparatus are not large enough to allow the pressure to be first adjusted, and a card taken quickly thereafter, as should be done to avoid superheating, because there would be a drop in the pressure on opening the cock to the indicator, and the time taken to regulate the pressure after opening the cock would be excessive. The steam supplied to the

reservoirs should contain considerable moisture, otherwise the steam in the reservoirs may be superheated at low pressures through throttling action.

There is a single three-way cock which admits the steam from one cylinder or the other, and which is also relied on in determining the atmospheric lines. This arrangement will not give correct results for the height of the atmospheric line if there is leakage in the three-way cock. In testing indicators we use two three-way cocks directly under the indicator, and turn both in taking the atmospheric lines, so that if there is a slight leakage in the first cock it is shut off from the indicator by the second.

There appears to be no definite way of knowing exactly where the water level is in the pipes which lead downward to the oil reservoir, and on changing the pressure it appears that the water level might vary to the extent of six or eight inches. If we wish to work with the greatest refinement, we should be careful to know exactly where the water level is and allow for it. In our apparatus for testing indicators a horizontal quarter-inch pipe, about 18 inches long, leads from the steam reservoir to a siphon, which is completely immersed in water. From this siphon, which is at all times full of water, a second horizontal pipe leads to an oil siphon, and from the oil siphon a third pipe leads to the rotating plug for measuring the pressure. With this arrangement the water level is always that of the horizontal pipe leading from the steam reservoir. The lower end of the rotating plug is at this level when in the mean position, so that we cancel out any effect of the water level.

It also appears to me that the connection from the two reservoirs to the indicator in Professor Read's apparatus should be more direct. In applying indicators, the best practice is to place them on straight connections as near as possible to the cylinder, one indicator being used at each end of the cylinder, and this feature should be copied as nearly as possible in testing an indicator.

Mr. Arthur L. Rice.—I have been working on an apparatus lately which is very much the same as the one described by Mr. Read. But I have done one thing which I think possibly is an improvement; that is, getting a longer port opening by shaping out the ports to the three-way cock and using a special plug which makes one revolution to two of the indicator, thus getting the opening and closing twice in the course of a revolution of the

plug. It gives me more nearly a square card, and therefore gives a little longer time for the settling of the indicator to its level if you want to run at high speeds. It seems to me that 150 revolutions for an indicator which is to be put on a high-speed engine is too slow; that you should test it on a higher speed if you want to take account of all the inertia effects of the piston and moving parts.

There is one matter upon which I would like to hear an expression of opinion from the members, and that is how to correct for the deficiencies of the indicator spring after you have tested for them. We have plenty of methods of testing to the last degree of refinement. We have very little opinion expressed as to how to correct for the defects of the indicator spring after you have found out what those defects are.

Professor Jacobus.—There is no way in which we can correct for the friction of an indicator. Any variation in the scale of the spring can, however, be readily allowed for.

Suppose we wish to calibrate a spring which has been used in obtaining diagrams for the high-pressure cylinder of a compound engine and that the card is as shown in Fig. 29. The first

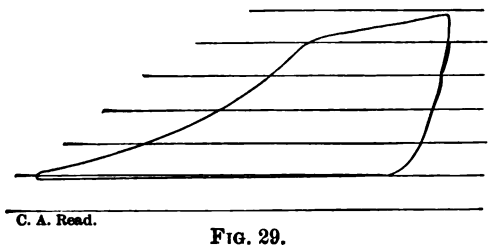

FIG. 29.

pressure at which the spring would be tested would be about that of the back-pressure line of the diagram, and calibrations would be made at five or more pressures, increasing by equal increments, until the maximum pressure used in the calibrations was about that of the admission line of the diagram. Let the horizontal lines in Fig. 29 be drawn at the average heights, as determined by, say, five calibrations at each pressure; then the proper scale to use, if there is but little variation in the scales, computed by dividing each pressure by the height of the corresponding line above the atmospheric line, will be the average of all the scales.

If there is considerable variation in the scale of the spring at

different pressures, determined as above, it may be caused by imperfect connection in the fastenings at the ends of the spring; and in a high-pressure card, as represented in Fig. 29, the scale may be nearly uniform if it is based on measurements taken from the line near the back-pressure line of the diagram instead of from the atmospheric line. Should this be the case, the scale to be used in the computations of horse-power should be the average of the scales determined in the latter way.

To correct for a varying scale, the equivalent corrected scale corresponding to the average indicator card is computed, and this is used in the computations for horse-power. To compute the equivalent scale, the horizontal lines obtained by the calibrations are laid off as in Fig. 29. The areas into which the indicator card is divided are multiplied by the corresponding scales, found by dividing the equal increments of pressure by the distance between each set of the lines, and the sum of the multiples is divided by the total area of the card to obtain the equivalent corrected scale. If the indicator cards are nearly uniform for an engine test, the equivalent scale computed for the average card may be applied to all cards. If, on the other hand, the cards vary greatly, the equivalent scale should be computed for two or more cards, and the scale corresponding to the area of each diagram should be used in the computations. The scale of a spring to be used on a low-pressure cylinder at pressures both above and below the atmosphere will often vary greatly throughout its range, the scale below the atmosphere being greater than that above the atmosphere, and the equivalent scale should be computed for springs of this class by the method just described.

Mr. Albert A. Cary.—I would like to ask Professor Jacobus if he makes any correction for the raising of the pencil and the falling of the pencil.

Professor Jacobus.—I make no such correction. I do not attempt to correct for friction, and do not believe, as I have said before, that such a correction can be made. This conclusion was arrived at after I made a series of tests where the friction of an indicator was varied by employing various sizes of pistons, and cards were taken simultaneously with this indicator and a second indicator which was in correct adjustment. These tests showed that the friction could not be allowed for, and also proved that if an indicator would withstand a certain test for friction, the effect of friction on the diagrams would be neglectable.

The test for friction just referred to is as follows: a constant pressure of steam is made to act on the indicator. The pencil is first pressed upwards and released, the indicator jarred lightly by striking it with a small wooden stick, and a line taken. The operation is then repeated, except that the pencil is pressed downward and another line is taken. If the two lines fall one on top of the other, or very nearly so, for every pressure to which the indicator is to be subjected, then the friction is not excessive; whereas, if they do not fall together, the friction is excessive. With excessive friction there may be steps, or right angles, traced in the expansion line, but even if this does not occur, there may be an error in the mean effective pressure.

Mr. Dean.—I should like to ask Professor Jacobus if he thinks it does any good to oil the piston of an indicator, and whether or not it makes any difference whether the cylinder of the indicator is horizontal or vertical.

Professor Jacobus.—We always oil the pistons. For high pressures we use ordinary cylinder oil, and for low pressures a lighter oil. I believe in thoroughly oiling an indicator, both when it is in use and when it is calibrated. In some cases oiling the piston of an indicator will not cause it to move freely, on account of the grit which is blown in the indicator along with the steam. A new engine will sometimes cut in the cylinder or at the valves; and if this occurs, it may be impossible to obtain correct indicator cards, even where the indicators are cleaned after taking each card. To obtain good results with an indicator, the friction must be reduced to a minimum, and to accomplish this, the piston should be thoroughly oiled.

I see no reason why an indicator should not give the same results with the cylinder either horizontal or vertical. All our calibrations of indicators are made with the cylinders vertical, but in applying them to engines we place them horizontal as well as vertical.

Mr. Dean.—I had a very dirty indicator once, and put it on a testing machine, and got the friction lines; then very carefully cleaned it and oiled it, and got the same amount of friction. I thought I would like to know what you had found.

Professor Jacobus.—If an indicator is not in correct adjustment, any amount of cleaning or oiling may not bring the lines together. The difference between the lines may amount to a sixteenth, or even an eighth, of an inch. Such excessive friction is often caused

by lack of alignment in the spring or the piston. In some cases, by reversing the spring end for end, most of the friction will disappear, because of a better alignment with the spring reversed than that which originally existed.

*Prof. C. A. Read.**—In regard to the suggestion of Professor Jacobus as to the time that the steam is admitted to the indicator, I find that with a little practice the operator can adjust the pressure and take the diagram in as short a time as is ordinarily taken in indicating an engine.

If I were to build another machine of this description, I should make the cylinders somewhat larger, although we have had no trouble with the present size. The large amount of exposed surface effectually settles any trouble as to superheated steam.

When it comes to the question of friction, I most fully agree with the gentleman that there is no way to correct for it. A well-made, well-cared-for indicator will have little friction before it is attached to the engine. What happens after it is attached is wholly problematic. I have tested an indicator and found it in excellent condition, and then attached it to the horse-power cylinder of a compound engine running 250 revolutions per minute, to determine the friction horse-power. The first card gave a good area, but each successive card had a smaller area, till finally the steam and back-pressure lines nearly coincided. The engine was a new one. The same indicator gave no trouble on an older engine running at 90 revolutions, with the same boiler pressure.

I would like to say, in connection with Mr. Dean's question, that the superintendent of one of the best known indicator companies claims that it is much better not to oil the piston of an indicator.

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* Author's closure, under the Rules.

No. 873.*

COMPARISON OF RULES FOR CALCULATING THE STRENGTH OF STEAM BOILERS.

BY H. DE B. PARSONS, NEW YORK, N. Y.

(Member of the Society.)

1. THE object of this paper is to attract the attention of engineers to variations in the rules now in use for determining the strength of the different parts which make up a steam boiler, with the hope that it may elicit a full discussion of the question whether or not it is desirable to prepare a set of standard rules for strength.

Universal standards, based on scientific methods coupled with experiment and experience, are now being adopted with advantage by both engineering and commercial interests.

Engineers have accumulated sufficient experience to predict with accuracy results that can be expected. Such predictions as to strength of boilers are foretold by calculations founded on analytical science, with constants supplied by experiment. Engineering literature is rich with records of these experiments, and the results obtained are in close enough accord for all practical purposes.

The author will not attempt a complete analysis of the rules in force, as most engineers are fully aware of the discrepancies, but will simply compare a few rules for the sake of illustration.†

DATA ASSUMED.

Type of boiler.....Scotch.
Mean diameter.....12 feet 7 inches = 151 inches.
Working steam pressure.....130 pounds above atmosphere.
Material.....Steel.
" tensile strength.....60,000 pounds.
Thickness of shell.....$\frac{7}{8}$ inch.

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* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† A lengthy comparison was made by Mr. N. Foley—see "International Engineering Congress," Division of Marine and Naval Engineering, Vol. II., 1894.

Joints, longitudinal.....Double butt straps of equal width, double riveted.
" transverse .....Lapped, double riveted.
Rivets, material.....Steel.
" diameter .....1 inch.
" pitch .....4 inches.
Flat heads, steam space, thickness .....$\frac{7}{16}$ inch.
Long stays, steel, spacing.....15 inches.
" fastening.....Double nuts, thinnest washer allowed.
Stay-bolts, spacing .....8$\frac{1}{2}$ inches.
" fastening .....Screwed, single nuts.

2. From the above data the working pressure allowed on the shell in pounds per square inch would be as given in Table I.

TABLE I.

I. United States Board of Supervising Inspectors of Steam Vessels....	139.0
II. Lloyd's Rules.....	116.8
III. Board of Trade	111.0
IV. British Corporation	118.6
V. Bureau Veritas.....	110.8

The difference is 28.2 pounds, or over 25 per cent.

The first rule makes no allowance for workmanship or proportions of joint. The other four rules include the percentage of strength of joint, while the third rule has a sliding scale for workmanship, shop methods, and general design.

3. The working pressure allowed on the flat heads in the steam space, when not exposed to the hot gases, and when the stays are fitted with double nuts and a washer on the outside, riveted to head and of minimum thickness mentioned in the rule, would be as given in Table II.

TABLE II.

I. United States Board of Supervising Inspectors of Steam Vessels....	184.8
II. Lloyd's Rules.....	128.0
III. Board of Trade	144.8
IV. British Corporation	127.9
V. Bureau Veritas	130.9

The difference is 56.4 pounds, or over 44 per cent.

The rules are not alike as to the size and thickness of the minimum riveted washer mentioned, and consequently the variation is largely due to the value of the constant employed.

4. Taking the data as assumed, and making the calculations

for a working pressure of 130 pounds, the results for the parts specified would be as given in Table III.

TABLE III.

Part of Boiler.	I. United States S. I. S. V.	II. Lloyd's Rules.	III. Board of Trade.	IV. British Corporation.	V. Bureau Veritas.
Thickness of shell, inches.....	0.8229	0.9594	1.0239	0.9532	1.0201
Nearest 32d	$\frac{27}{32}$	$\frac{31}{32}$	$1\frac{1}{32}$	$\frac{31}{32}$	$1\frac{1}{32}$
Thickness of flat surfaces, screw stay-bolts, 8½-inch centres, fitted with nuts, inches.....	0.5531	0.5531	0.5232	0.5338	0.4842
Nearest 32d	$\frac{18}{32}$	$\frac{18}{32}$*	$\frac{17}{32}$	$\frac{17}{32}$	$\frac{16}{32}$
Area of long steel stays, square inches	3.656	3.656	3.250	3.262	3.259
Diameter—nearest 16th	$2\frac{3}{16}$	$2\frac{3}{16}$	$2\frac{1}{16}$	$2\frac{1}{16}$	$2\frac{1}{16}$

5. Certain essential details are not provided for by some of the regulations, but are in others. Some inflict penalties for poor workmanship and defective design, while others allow the same pressure on the best as well as the poorest boiler when made from the same material. Corrosion is provided for by the addition of a fixed thickness to the calculated part under some regulations, while in others it is included only in the general factor of safety. This factor of safety necessarily differs in all the regulations.

The author is not aware that there have been any more failures under the regulations giving the minimum thickness than under those of the maximum. If the minimum is ample, why use the maximum? If, under the high pressures now maintained, the maximum is needed for safety, is it not opportune to increase the minimum? If the minimum is sufficient, then from Table III. it will be apparent that under any one regulation the boiler is not of equal strength throughout its parts, nor is there the same allowance for the more rapid corrosion of certain parts over others. Thus, if the shell thickness under Regulation I. be correct, it is not necessary to have it as heavy as under Regulations III. and V., while the staying of Regulations III. and V. are lighter than in Regulation I.

6. The author does not desire to present this paper as an

* $\frac{17}{32}$ is too thin, but for $\frac{18}{32}$ pressure could be 151 pounds, or nearly 17 per cent. more than required.

argument either for or against the idea of appointing a committee to consider and draft a set of regulations, but does so with the hope that the members will freely express their opinions on the question. If a committee be appointed, the author would suggest that the committee contain as members representatives of the various recognized regulations, so that the rules proposed may have a universal standing.

APPENDIX.

Below is appended a short statement of the regulations referred to above:

Meaning of Letters.

S denotes tensile strength in pounds per square inch.
S_1 " " " " tons " " "
t " thickness of part in inches.
T " " " parts in sixteenths of an inch.
D " mean diameter of shell in inches.
B " least percentage of strength of joint.
C " constant.
p " pitch of stays in inches.
a " spacing of rows of stays in inches.
W " working pressure in pounds per square inch.

Cylindrical Shell.

United States Board of Supervising Inspectors of Steam Vessels:

$\frac{1 \times S \times 2 \times t}{6 \times D}$ = working pressure, to which add 20 per cent. for double riveting.

Lloyd's Rule:

$$\frac{C \times (T - 2) \times B}{D} = \text{working pressure.}$$

Board of Trade:

$$\frac{(S \times B) \times 2 \times t}{D \times C} = \text{working pressure.}$$

NOTE.—In this rule C is a minimum factor of safety, with additions according to circumstances.

British Corporation:

$$\frac{C \times (T-1) \times B}{D} = \text{working pressure.}$$

Bureau Veritas:

Calculates rupture through "Plate," "Rivets," "Plate and Rivets," "Butt Straps," and "Butt Straps and Rivets." Uses the minimum pressure so found. Formulæ allow 0.04 inch in thickness for corrosion.

Flat Surfaces.

United States Board of Supervising Inspectors of Steam Vessels:

$$\frac{C \times T^2}{p^2} = \text{working pressure.}$$

Lloyd's Rules:

$$\frac{C \times T^2}{p^2} = \text{working pressure.}$$

Board of Trade:

$$\frac{C \times (T-1)^2}{(a \times p) - 6} = \text{working pressure.}$$

British Corporation:

$$\frac{C \times (T-1)^2}{a \times p} = \text{working pressure.}$$

Bureau Veritas:

$$\frac{(T-1)^2 \times S_1}{(a^2 + p^2) \times C} = \text{working pressure.}$$

Steel Stays.

United States Board of Supervising Inspectors of Steam Vessels:

For stays not exceeding $2\frac{1}{2}$ inches effective diameter, 8,000 pounds per square inch of section. Stays exceeding $2\frac{1}{2}$ inches, 9,000 pounds.

Lloyd's Rules:

For stays not exceeding $1\frac{1}{2}$ inches effective diameter, 8,000 pounds per square inch of section. Stays exceeding $1\frac{1}{2}$ inches, 9,000 pounds.

Board of Trade:

For stays, when material has tensile strength from 27 to 32 tons, 9,000 pounds per square inch.

British Corporation:

$$\sqrt{\frac{a \times p \times W}{8{,}000}} + \tfrac{1}{8} = \text{effective diameter, inches.}$$

Bureau Veritas:

$$\sqrt{\frac{a \times p \times W}{300 \times S_1}} + \tfrac{1}{8} = \text{effective diameter, inches.}$$

DISCUSSION.

Mr. R. S. Hale.—Mr. Parsons's paper is a very interesting one, in bringing out the different results obtained when using various standard rules for boiler designs. The practice of the Mutual Boiler Insurance Company, for which I am consulting engineer, may not be absolutely correct, and may not be the best, but a statement of our practice may show the difficulty in establishing any set of standard rules.

Taking up first the question of the cylindrical shell, I will refer to the horizontal return tubular boiler, as by far the great majority of boilers which come under our inspection are of this type.

The factors covering the pressures to be allowed on these boilers are thickness of the plate, the strength of the metal, the efficiency of the joint, and what may be called the moral factors, such as the design of the boiler, the workmanship during construction, and the use to which the boiler is put. In regard to the efficiency of the joint, we always compute this from the strength of the metal and of the rivets. We do not, however, often find it necessary in new boilers with butt-strapped joints to consider particularly the strength of the rivets in shear, since, if the joint is properly designed for a tight joint, the rivets are usually much stronger than the plate. On lap joints this is not necessarily the case, but lap-joint boilers are now very seldom put in by our members, except for heating purposes, where the pressure carried does not exceed 15 pounds per square inch, and where the margin of strength is very high.

In regard to the tensile strength of the metal, it is our custom to specify that the tests of coupons in the sheets shall not be less than a certain amount, usually 55,000 pounds per square inch, nor more than a certain amount, usually 65,000 pounds per square inch. We also specify that the elongation in 8 inches shall not be less than a given amount, usually 25 to 30 per cent.,

and that the phosphorus and sulphur shall not exceed certain limits, usually .035 per cent. These requirements represent the usual mild steel specifications. So long as the metal comes up to the specifications called for, we pay no attention to the exact tensile strength found on the test, but design for the moderate stress in the weakest point in the riveted joint of 12,000 pounds per square inch. This corresponds to a factor of safety of 5 if the strength of the metal is taken as 60,000 pounds per square inch, or to a factor of about 4½ if the tensile strength is taken at 55,000 pounds per square inch.

We make no allowance for future corrosion in the design of the boilers, except in so far as we use a lower unit stress in designing than we consider safe, so that even with some slight corrosion the boiler can still be run at the pressure for which it is designed.

The above data determine the pressure on new boilers built to our specifications, and we expect that such boilers will be able to carry their pressure for many years without any necessity to reduce it. Of course, if a boiler shows signs of distress or severe corrosion, it might be necessary to cut down the pressure, but we consider that a boiler with metal of the above quality and with butt-strapped joints is safe, even if the metal is stressed considerably above 12,000 pounds per square inch, so that there is a considerable margin for corrosion or other troubles.

In the case of a boiler which is submitted to us for inspection and insurance we adopt the same rules as above given, but in this case we cannot give our members any assurance that they will be able to carry a pressure corresponding to a unit stress of 12,000 pounds per square inch on their boilers for any length of time. However, on boilers with the butt-strapped joint, where we have reasonable grounds to believe that the metal is of good quality, there is but slight probability that we should find it necessary to cut down the pressure, and we even allow higher pressures to be carried after giving notice that such higher pressures may be only temporary.

On old boilers, however, where the joints are lap joints, and most especially where these joints are exposed to the fire, we never allow a greater pressure than that corresponding to a unit stress of 12,000 pounds per square inch (factor of safety of 5). It is true that in occasional cases, when cutting down the pressure would involve shutting down the whole steam plant, we sometimes allow a higher pressure for a few months until new boilers can be procured.

In special cases, such as very old boilers showing signs of distress, we do not even allow as high a pressure as this.

It will thus be seen that our rule corresponds to the English Board of Trade rule, except that we take a fixed value for the strength of metal, and that our C is an average factor of safety for which we make allowances in the cases of boilers which are especially well designed and made, and additions only in the case of old boilers which show signs of distress.

Of course the rules stated above apply only to the mild steel which is now universally used for boilers. We were recently asked to insure some boilers which were to be built of nickel steel. We went into the subject as thoroughly as we could at the time with the literature and tests available, and finally told the parties who wished to build these boilers that we were prepared to allow a unit stress considerably above the 12,000 pounds per square inch which we allowed on mild steel, and that the excess would depend largely on the quality of nickel steel which they proposed to use, and the specifications to which it was made. The boilers were, in the end, not built, so that the question was not considered further. We also have a number of old iron boilers under ur charge on which we usually allow 8,000 to 10,000 pounds stress on the metal. These boilers, however, are almost all made with lap seams, and we are encouraging our members to replace them as fast as possible with a safer type.

All the above discussion refers to horizontal return tubular boilers. We also have under our charge a large number of vertical tubular boilers, both of the ordinary type and of the Manning type. On these we adopt the same general rules with the exception that our specifications as to the quality of metal are not quite as stiff, since the metal of the outside shells is not exposed to the heat of the fire, and we also allow a slightly greater stress on the metal of the outside shells, going up as high as 13,333 pounds per square inch, corresponding to a factor of safety of $4\frac{1}{2}$, if the tensile strength be taken as 60,000. On old boilers of this type with lap seam joints we are averse to allowing more than 12,000 pounds per square inch stress in the metal. On new boilers with butt strap joints and metal of good quantity we should not be afraid to allow 15,000 pounds per square inch, corresponding to a factor of safety of 4, provided our members understood that this pressure might be reduced at any time.

In regard to stayed surfaces we have two cases to consider.

First, in horizontal tubular boilers. In these we stay the heads preferably with through and through rods of large size, say, of about 2 inches diameter, with channel bars or angle bars riveted to the heads to stiffen them. On these rods we allow a stress of 9,000 pounds per square inch.

On the fire box of vertical tubular boilers we have usually adopted the United States rule. This gives the highest pressure of any of the rules in common use, but even in large boilers with the fire box six or seven feet in diameter, the fire box is, to a certain extent, self-sustaining, so that we have thought the rule gave ample margin, particularly as we know of very few cases of failure of boilers at this point.

On small vertical tubular boilers, of which we have quite a number under inspection, even the United States rule would require a very much larger number of stays than is found practically necessary. We have had occasion to design but very few small boilers of this type, as most of the boilers under our inspection were already at work when brought to us for approval or to determine a pressure. In the latter cases we have computed the permissible pressure by the United States rule, and also the permissible pressure considering the fire box as a collapsible flue. If the sum of these two pressures, *i.e.*, the pressure which the fire box will carry as a collapsible flue, added to the stiffening effect of the stays, was greater than the pressure which the user of the boilers desired to carry, we have considered ourselves safe in allowing that pressure, and have never had any difficulty.

As will be seen from the above statement, there would be great difficulty in adopting any rules which could take into account all the different factors of different qualities of metal, different design of joints, different grades of workmanship, different allowances for corrosion, and differing services for which the boilers are to be used. At the same time full discussion of all these questions would be of great value to designers and insurers of boilers.

Mr. F. A. Scheffler.—This paper is one of the most important papers ever presented to the Society. The writer has had considerable experience in designing and constructing boilers of various kinds, but never before have I fully realized that there is such a discrepancy between the "rules" used by various important supposed-to-be authorities as is briefly and tersely set forth in Mr. Parsons's paper.

Personally, I believe that the best rule as to strength of shells

is the one used by the Board of Trade, as the strength of joint is taken into consideration, which, in my opinion, is the only proper way to obtain the true strength of the shell. It is surprising that, with all the brains which our government has at its command, no one at Washington has had the sense to correct or revise the loose rule now in existence for determining the strength of shells.

This rule is so old that you can almost see the gray hairs on it. It is wrong in more ways than one, but I call attention to the fact that 20 per cent. is not always the increase in strength of the joint by double riveting. One can design a joint in double riveting which will only increase the strength 10 per cent., or which will increase it 30 per cent., if the single riveted joint with which it is compared is a bad one. Query: Does the department allow 30 per cent. additional pressure for a triple riveted joint?

On the other hand, the Board of Trade's rule for flat surfaces is not so conservative, and some of the others are better.

I am heartily in favor of appointing a committee to endeavor to adopt some standard which will be used all over the world, and trust this matter will meet with the attention it deserves in the hands of our Society.

Mr. Edward P. Thompson.—Common sense is a rule which has been referred to. Yet that is a most indefinite term. I have become interested lately in the strength of steam boilers, and find there is no common sense about a certain feature, so far as I can see. Not long ago I was called upon to make an examination in connection with a blow-out of a locomotive. The locomotive was going down grade, and some unusual sound was heard. The engineer saw the fireman blown off the locomotive and rolling down the bank. After being picked up he was found to have been scalded, and that is the way he met his death, rather than by the tumble he had. He was able to testify, however, a little while afterward, before he died, and he merely thought it was a blow-out of a tube, and in that case, of course, it would be looked upon as an ordinary occurrence and something which could not well have been prevented. But in this particular instance it could have been prevented, and if this practice of plugging boilers is kept up there will be plenty of accidents of that kind. There have probably been a great many accidents which we have never heard about—cases where the party injured does not make any complaint. This was the nature of the accident: The foreman had ordered some tubes at the lower part of the boiler to be removed,

and "common sense" in this case was merely a name for a certain practice with which he had become acquainted, and therefore it was common sense to him. Others had done it, and therefore he could do it, and that is what his common sense was. He plugged up the twelve holes where the six tubes had been taken out. If you take out half a dozen tubes which act as ties to hold the heads together, the boiler will be that much weaker. That is mathematical reasoning. I believe in basing rules upon reason rather than upon common sense, because people have different ideas about common sense. He plugged up the holes. It was difficult to determine whether these holes were plugged up by threading the plugs or by merely driving them in. One witness held they were merely driven in. Another held that they were threaded. But it is quite immaterial, because a plug can be driven out when a tube could not be blown or burst. When the plug is in instead of the tube, you not only have the boiler weakened so as to allow the blowing out of the head, but the pressure upon the plug will be greater and more apt to produce the accident than if the tube is there, because the pressure can act longitudinally upon full end surface of the plug. Say the plug is 6 to 7 inches square in area, as it could easily be—perhaps about 6 square inches; multiply that by the pressure that they had—70 pounds—you will see there is a great deal of pressure upon that plug to blow it out. The only reason that somebody was injured in this case was that the man happened to open the door of the fire box, and happened to be standing in the way of the plug when it was driven out. But how many know how many plugs have been driven out, and people injured for life? So it would seem as if it were a matter of almost sufficient importance to have legislative action. But why should a body of intelligent engineers be forced to adopt a simple rule forbidding that plugs shall be employed where tubes have been removed for cleaning or for any other purpose?

Prof. H. W. Spangler.—It would seem to me that this question is largely a question of insurance. I have found in a number of cases where I have had boilers under my charge that the rules of a certain insurance company would not allow the boiler to be insured under that company with the dimensions which the boiler had and with the pressure which is to be carried. I have found that the insurance companies were always very amenable to reason, however, and that their rules would be modified if there

was good reason for doing it. As far as the rules given in Mr. Parsons's paper are concerned, they are practically, as far as foreign work is concerned, the rules of the insurance companies. As far as the United States rules are concerned, they are those rules which must be followed by vessels which are to be used in the navigable waters of the United States. If you are going to insure in a particular company, you want to build what that particular company is willing to insure after it is built. If you are willing to insure yourself, it seems to me you should design as you know is right, if you do know. I am satisfied that the rules of the United States supervising inspectors are far from being the best rules for the building of boilers which can be devised; but those of us who have had to deal with the foreign insurance companies, and have kept track of their rules for years, know that those rules are constantly being modified by their experience; and their experience, to my mind, is that common sense to which one of the speakers referred to to-day. Therefore, if one wants to insure his boilers, it seems to me it is nothing more than sensible that he should build his boilers as insurance companies call for. If those rules are not right, there is not much difficulty, if you get at the engineering side of the insurance company, in convincing them that the boiler you propose to build or to buy will do its work quite as satisfactorily as the boilers which they say they will insure. I have found there is very little difficulty in the handling of properly built boilers, although they may not be built exactly as the rules call for.

Mr. William Kent.—There was a long paper on this subject presented at the Engineering Congress in Chicago, in 1893, by Mr. Nelson Foley. Those who are interested in this subject ought to see that paper, as the author suggests in his note.

In regard to the United States rules, I think they have been condemned by every authority who has ever written on the subject. They are known to be less safe than any other rules, and the foreign rules, the Board of Trade, Lloyds, the Bureau Veritas, and others, are, as Professor Spangler says, being constantly modified by experience, while the United States rules are not modified by experience or anything else. They have been condemned by writers for the last 25 years, and they remain in the same old fossilized condition in which they always have been, with the single exception known to me, that a few years ago the Board of Supervising Inspectors did discover, 20 years after

other people had discovered it, that the neck form of test piece was not a good one for steel. I believe the rules still allow that neck form for iron. Years ago it was not good for either iron or steel, and the United States Board of Supervising Inspectors only four or five years ago did find out that it was not good for steel.

I am sorry that Mr. Parsons has this sentence in his paper: "The author is not aware that there have been any more failures under the regulations giving the minimum thickness than under those of the maximum." Mr. Parsons is enough of a lawyer to know that negative testimony is not good testimony. The fact that he did not see a man kill another is no proof that the man did not kill the other. But on the other hand the experience of the insurance companies of this country and the experience of foreign countries is that boilers ought to be built about as these foreign rules lay down. And they do not differ so much among themselves. For instance, the working pressure allowed on the flat heads, when not exposed to the hot gases, and when the stays are fitted with double nuts and a washer, etc., is 127, the British Corporation, and 144, Board of Trade, the two extremes, while the United States rules give 184 pounds. The working pressure allowed on the shell in pounds per square inch varies from 110 to 118 according to the foreign rules, while the United States rule gives 139 pounds. So the United States rule is the only one which is very far away. I think, if we want to build boilers, if we build them according to foreign rules or according to the rules of the American Insurance Companies, they will be all right.

I wish to put on the board a formula which I published years ago, and which I think a pretty good one for strength of shell of the boiler: Working pressure equals 14,000 times the thickness in inches, divided by the diameter in inches, $W = 14{,}000\ t \div d$. That, you see, is independent of the actual tensile strength of the steel. It is based on the supposition that the factor of safety of 5 is correct for 50,000-pound steel; a factor of 6 for 60,000, and a factor of 7 for 70,000. That is to handicap the higher carbon steel. As every one who knows anything about the manufacture of fire boxes knows, the very best steel you can get is the softest. So to prevent men putting in high carbon steel we handicap it by giving a higher factor of safety. It is also based on a rivet seam factor of 0.70, which will do for a very well-designed lap joint. Of course a lower factor can be used, in the engineer's

judgment, if he uses butt joints and is careful about the manufacture of the plate and inspection, tensile strength, and all that. He might raise the figure of 14,000 higher if he is satisfied with a lower factor of safety.

Mr. George I. Rockwood.—Boiler makers in America, I think, have fallen into the way of not using any authoritative rules of a general nature in designing steam boilers, but rather they apply the rule of common sense and arithmetic to each individual case. So that I think the paper would have less interest for us than would be the case were we Englishmen, Frenchmen, or Germans. No doubt the Navy uses the Navy rule, but certainly designers of land boilers do not use it.

Nevertheless, it seems reasonable that we should have some authoritative expression on the subject, especially with reference to the proper factor of safety for each part of a vessel, of whatever shape, built to contain high-pressure steam. I agree emphatically with the author that a committee to investigate and report upon suitable rules would be a wise one to create.

Mr. Henry I. Snell.—I would like to make a suggestion in connection with the idea just advanced, and that is, if this committee is appointed, they also be requested to formulate a rule by which the boiler shall be taken care of after we get it.

We all know that safety depends as much upon the man who has the boiler under his charge as upon the designer or builder.

I have had considerable experience in being around boilers, oftentimes in positions from which it would be difficult to escape in case an explosion occurred. I have learned that explosions occur more frequently from strong and well-made boilers than from old or weak ones. A little thought will suggest that in the one case we depend upon the strong boiler to stand any and every usage, while in the other the engineer protects his own and other lives with his care and watchfulness.

I recall a boiler which some years ago was in use on the East Boston Ferry, and had been for many years, until it had nearly all rusted out, with some of the plates so thin I have seen the engineer thrust a blade of his penknife right through them. This boiler, before and after this time, was in daily use, carrying thousands of passengers from East Boston to the city proper.

It was one of the usual type of ferryboat boilers of that period; about 10 feet in diameter and 30 feet or 40 feet long.

No serious accident ever happened to this boiler because the

engineer knew it was weak and watched it carefully; never taxing it beyond its strength; never taking any chances about his water.

In Philadelphia there are over 10,000 boilers in daily use. The boiler inspection laws there are very severe, and boiler manufacturers want to put on a little extra price for goods intended for this market. Since the boiler explosion at Wilt & Sons planing mill, on Front Street, Philadelphia, when four men were killed (June 27, 1879), I recall but two destructive explosions of boilers in the city of Philadelphia, where loss of life occurred, and both of these were boilers of first-class construction. One occurred at the Edison Electric Light Station, and caused much litigation; the other at the Baldwin Locomotive Works, both resulting in a loss of life. These were what might be called strong and safe boilers, which would probably comply with all the different formulæ given in this paper, and perhaps with what new formulæ our proposed committee may formulate.

I know of many explosions in other cities, and generally they occur in strong, well-designed, but sadly neglected boilers. From these experiences, I am of the opinion that care of the boiler is as necessary a requisite for safety as strength, and that our committee, if we appoint a committee, be advised to study well Dr. Holmes' specifications of the "One Hoss Shay," and give us an admonition to have the "Deacon" always in charge of our boilers.

Mr. D. W. Robb.—I wish to second this motion which has been made, and in connection therewith I would say that I think this subject is of very great importance, well worthy of being taken up by the Society, and well worthy, if possible to obtain it, of an international commission. I think that engineers all over the world, particularly where they are interested in marine boiler work, should see the importance of this. I have had experience under the Canadian rules, which are similar to the Board of Trade rules, and while these are fairly satisfactory, there is more or less trouble because the rules are not sufficiently complete and not always consistent, and, as a matter of fact, it is not safe to undertake the construction of marine boilers without making special plans in almost every case, which have to be submitted to the local inspector, and in many cases to the department at Ottawa. This, of course, causes a great deal of delay; material cannot be ordered, and customers are kept waiting until all the details are settled.

In regard to the general question, it seems to me that it should be, as Mr. Parsons stated, possible to formulate rules which would apply to the construction of the usual forms of boilers. But the effects produced by the destructive elements, heat, pressure, and corrosion, are very intricate, very troublesome, and very hard to protect against, and for that reason we find these variant rules and variant factors of safety. As some one a long time ago expressed it, "the factor of ignorance" is very prominent. But it seems to me that it should be possible to formulate rules which would be fairly satisfactory, and make a great saving to the customer as well as to the manufacturer, and that the factor of ignorance could be at least agreed upon.

A point which has been touched on by one gentleman here, I think, is of the very greatest importance, and perhaps the vital point of the whole thing, and that is inspection during construction. You may have your materials all right, and your rules all right, or as near right as possible, but the boiler may be entirely spoiled during construction, and I think that this question of inspection is harder to deal with and requires closer attention than any other point; it is something which perhaps can only be dealt with by the government of the country. Although it may be difficult to get the various governments, insurance companies, and other bodies to adopt anything uniform, it seems to me worth trying for, and that it is a good object for the Society. I, therefore, second the motion.

*Mr. Parsons.**—In presenting the paper, the author endeavored to lay facts before the Society, without any expression on his part either *pro* or *con*, as to the question whether it would be wise or not to appoint a committee to draft a set of rules for calculating the strength of boilers. The author makes the suggestion, if it is deemed wise to appoint a committee, that an effort be made so to form the committee that it shall contain as members representatives of the important regulations, in order that the rules as determined upon may have a universal standing. Such rules could be amended to keep pace with inventions and improvements in the same manner as they were formed.

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* Author's closure, under the Rules.

No. 874.*

A NEW RECORDING AIR PYROMETER.

BY WILLIAM H. BRISTOL, HOBOKEN, N. J.
(Member of the Society.)

THE instrument herein described has been designed to meet a demand for a pyrometer to measure temperatures of high ranges, and to give continuous records of changes of such temperatures on a moving chart; also to produce an instrument which would be self-compensating for barometric and thermometric changes of the atmosphere without introducing delicate mechanism which would tend to inaccuracy and to preclude its use for commercial purposes.

The diagram (Fig. 30) shows the arrangement of the parts of the pyrometer, which consist simply of a porcelain bulb connected by a capillary tube to a recording pressure gauge. The stem of the porcelain bulb is made of sufficient length to pass through the furnace wall. The capillary connecting tube is made of seamless copper. The recording pressure gauge employed is constructed on the same plan as those previously described.† By reference to the description it will be found that each pressure tube or spring is constructed on the Bourdon principle, and consists of a tube of closely flattened cross-section formed into a helix of two complete turns.

Two of these pressure tubes or springs are employed in the recorder—one of these, the indicating tube or spring, being connected to the air bulb by the capillary tube, and adapted to be turned axially by the variations of pressure due to changes of the temperature to be measured; the other, a compensating spring, is mechanically attached to the free end of the indicating tube or spring.

The compensating spring is adapted to be turned axially by

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* Presented at the New York meeting, December, 1900, of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† *Trans. A. S. M. E.*, page 225, paper No. 368.

variations of atmospheric pressure and temperature in a direction opposite to the motion of the first or indicating spring under the same influences.

Fig. 31 shows an interior view of the recording portion of the instrument. The compensating and pressure tubes are lettered respectively *A* and *B*. These tubes are made of equal strength, hence external or internal pressure will produce the same angular movement in each.

The air bulb, capillary connecting tube, and indicating spring

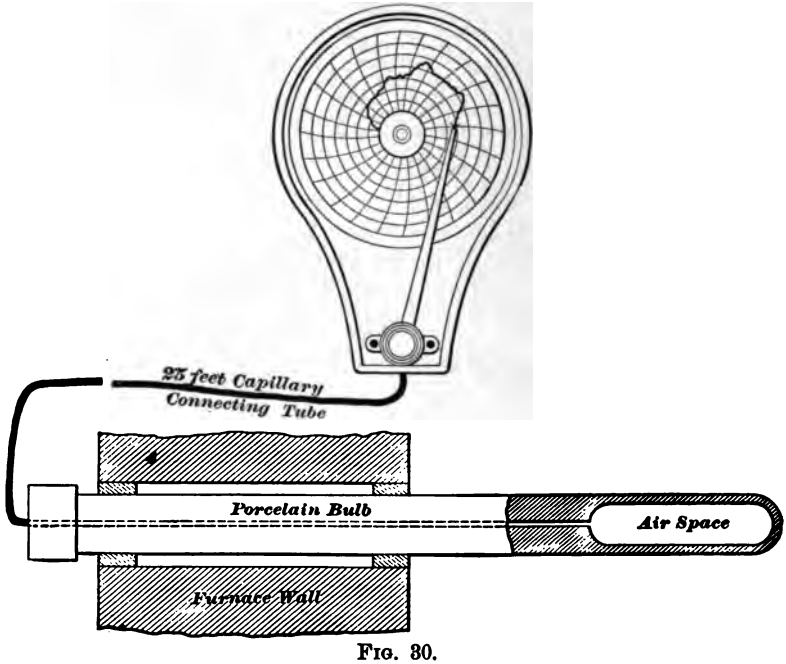


FIG. 30.

are almost exhausted of air, so that when the air bulb is cold, it is subjected on the exterior to nearly atmospheric pressure; but when the bulb is exposed to high temperatures, the remaining inclosed air is expanded so as to practically balance the external pressure, and the bulb is relieved of strains which would, in its weakened condition, tend to injure it.

Fig. 32 shows the indicating and compensating springs of the recorder on an enlarged scale. *C* is the bracket to which one end of the indicating spring *B* is secured; *D* represents a portion of the capillary connecting tube where it enters the

stationary end of the indicating spring. The compensating spring *A* is helically formed in the same direction as the indicating spring, but of a larger diameter, so that it may be placed outside of and concentric with the indicating spring, as shown, and is mechanically attached at *E*, there being no opening or connection between the interiors of the two springs. At the

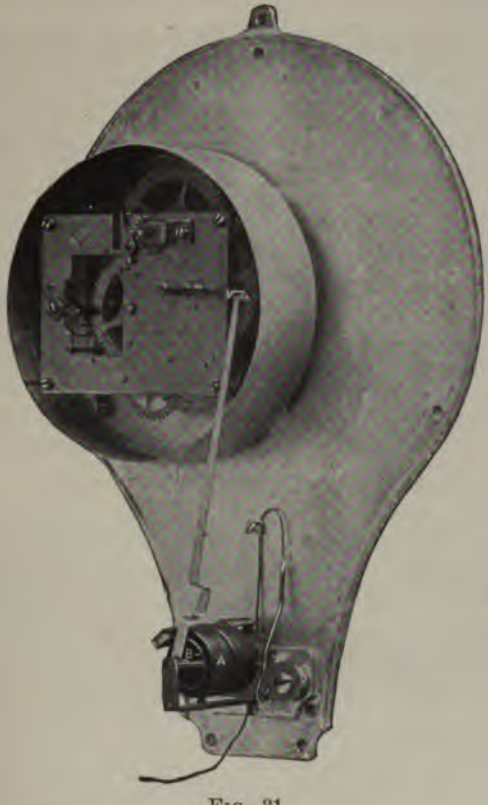


Fig. 31.

free end of the compensating spring a bracket *F* is soldered, making a rigid connection to a shaft through the centre of the springs. At the front end of the shaft the recording arm *G* is rigidly secured.

To illustrate the operation of the compensating spring, assume that the air has been partially exhausted from it, and that the barometer rises. Under such a condition the indicating spring would turn to the left (Fig. 32) if the compensating spring

was not present—that is, in direction of arrow 1; but the compensating spring *A* being present, and tending to turn to the right, as indicated by arrow 2, through the same angle, the effect of changes in atmospheric pressure is neutralized, and the position of the recording arm is unaffected by the rise of atmospheric pressure. For the same reasons there would be no movement of the recording arm when there is a fall in atmospheric pressure.

If the air is not entirely exhausted from the compensating spring, it will also compensate for thermometric changes in the same manner, the indicating spring tending to turn in the direction of arrow 1 when the temperature falls, and in the direction of arrow 2 when it rises; while the compensating tube will be turned in opposite directions equal amounts under the same influences. By leaving the proper amount of air in the compensating spring the compensation may be made perfect for any change of atmospheric temperature, provided the air bulb is at a given temperature. The error for small variations from the average temperature to be measured will be so small that it may be neglected. As the tubes are turned in opposite directions by barometric and thermometric changes it is evident that there will be no movement of the recording arm unless due to changes of pressure communicated to the indicating spring through the capillary tube from the air bulb exposed to the temperature to be measured.

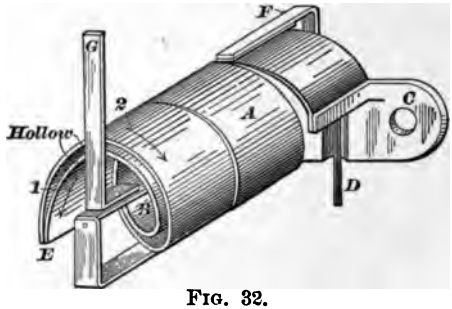


FIG. 32.

The helically formed pressure springs are particularly well adapted for use in this instrument on account of the small internal space, which, together with that of the capillary connecting tube, forms a small volume in comparison with that of the air bulb.

Thus far, special attention has been given to working out the mechanical features of the instrument, and to determine experimentally on the most practical form of the porcelain air bulb, and how these bulbs may be applied to continuously record high temperatures. As the volume of air space outside of that exposed to the temperature to be measured is very small, and as there are no corrections or computations necessary for barometric or thermometric changes, it will be a simple matter to calibrate the instrument according to the theory of the air thermometer, which is a recognized standard for measuring temperatures. The instrument here exhibited has been calibrated by comparison with a standard from 32 degrees up to 600 degrees Fahr., and by the melting points of aluminum and copper for the scale up to 2,000 degrees Fahr.

This instrument is the joint invention of E. H. Bristol and the author.

DISCUSSION.

[NOTE BY THE SECRETARY.—The author presented this paper by illustrating the instrument's construction and action for the purposes for which it was intended. Questions were asked him as to its features by individual members covering the following points :]

Mr. A. A. Cary.—I would ask, as to the provisions for transporting the instrument and as to its practicability for use in boiler testing, where it would have to be carried from one plant to another? May we be told also as to the allowance for friction of the recording pen on the paper?

Mr. Henning.—I want to ask concerning the accuracy with which scales could be read with temperatures running above 2,000, and how the scale is graduated?

Mr. Kent.—Can the author speak as to its availability in boiler testing when furnace temperatures might run up to 3,000?

A member inquired whether the bulb would stand plunging into molten metal and why platinum could not be used instead of porcelain.

Mr. D. J. Lewis.—I would ask as to the effect when the connecting tube might have to pass through different temperatures, as, for instance, to a warm room from a cold condition out of doors?

Mr. Henning.—In Europe porcelain tubes have been used for some considerable time, and when they remain continually in the furnaces they give perfect satisfaction. I do not know whether

they have been used for instruments which are to be carried round, because the china becomes brittle after an exposure to high temperature for long periods.

Mr. O. C. Woolson.—I do not want to discourage Mr. Bristol, but the temperatures about which we are particularly interested run over 2,700 or 3,000 degrees. It takes from 2,000 degrees to 2,300 degrees Fahr. to melt cast-iron, and steel somewhat higher, and I should assume that a pyrometer to record at 2,300 degrees would be more accurate if able to run to 2,600 or more degrees. Now you take the matter of boiler-flue temperatures, and you can get it pretty accurately in the uptake, as the gases go into the stack, with simple instruments; and then we must guess at a quarter, and multiply by four, for temperatures in other passages, because of the lack of a convenient and practical pyrometer to get into such places with a much higher temperature, without setting up a laboratory at great expense. We want to get in the front end of the boiler, and right over the furnace.

Mr. Bristol.—I hope that I shall be able to succeed.

Mr. Trump.—I would say we have made some experiments with porcelain tubes in taking temperatures in furnaces up to 2,000 degrees C. similar to those made in Germany, and apparently they stood the work perfectly, except that after being in such a high temperature they were very friable and apt to break. The glazing stood all right. We have also used, I think, one of Mr. Bristol's thermometers of this same kind—perhaps it had not the compensating feature—and used it for a recording thermometer in experiments in the burning of lime where we introduced it directly into the lime chamber, and it stood all right, and did its work for a long period of time, giving very good results. We are also using the same Bristol thermometer in recording the temperature of boilers before and after economizers. That of course is rather a lower temperature; but we have tested it alongside of the regular nitrogen thermometers, and have had no trouble with it at all. It gives a very legible record and is a very practical instrument. We like it very much indeed, because it is portable and is comparatively inexpensive. The great trouble with the Chatellier thermometers and thermometers of that character is that they are very difficult things to keep in adjustment. They are not at all simple. The electric measurement is difficult to correct, and a simple form of thermometer of this kind is very much needed in our work.

Mr. F. W. Dean.—How is the pyrometer to be supported in a furnace?

Mr. Geo. N. Comly.—What is the length of tube which it is desirable to expose to heat?

Prof. Gaetano Lanza.—What are the usual precautions to get the air dry?

*Mr. Wm. H. Bristol.**—Replying to the various questions which have been asked, I would answer as follows:

To Mr. Cary's question as to provisions for transportation of the instrument, and as to its practicability for use in boiler testing, I would say that thus far none of the completed instruments have been packed and shipped, but as the porcelain bulbs are imported from Germany, and I have received quite a number which have arrived in perfect condition, I see no reason why, if proper precautions are taken in packing, that the completed instrument could not be successfully shipped by the usual methods.

Answering question as to allowance for friction of recording pen on paper, I would state that no allowance is necessary, as there is none. Capillary attraction would alone be sufficient to make an ink record without having the pen point actually in contact with the chart, but in practice the pen is arranged to touch the paper very lightly. The slight friction produced gives an even record and keeps the pen arm from being affected by external vibrations.

As to the accuracy to which a scale reading of over 2,000 degrees could be read, I would say that charts are made of 8-inch and 12-inch diameter. On the 8-inch chart the movement of the pen arm for 2,000 degrees is about $2\frac{1}{2}$ inches, and on 12-inch chart it is about 4 inches. On the large chart a variation of 10 degrees Fahr. would probably be readable.

The scale on the model exhibited was graduated by comparisons with a standard glass gas-filled thermometer for temperatures between 100 degrees and 600 degrees Fahr., the bulbs of both the standard and the recording being simultaneously immersed in oil. For the upper portion of the scale the position of the pen was marked for the melting point of copper (1,930 degrees Fahr.) in a furnace which was uniformly heated. The other portions of the scale were then interpolated, accuracy being

* Author's closure, under the Rules.

insured by the fact that air expands at a uniform ratio for equal increments of temperature.

In reply to Mr. Kent, regarding application of these instruments for furnaces running up to 3,000 degrees Fahr., would say that up to the present time I have only tested and had them in actual operation in furnaces running up to 2,000 or 2,200 degrees Fahr. Until I have had time to make experiments for these higher temperatures, I am not prepared to say whether the porcelain bulbs will successfully stand. Judging from Mr. Henning's observation that porcelain bulbs are used abroad to 2,750 or 2,800 degrees Fahr., it seems quite possible that they will stand 3,000 degrees Fahr.

Replying to inquiry why platinum could not be used, would answer that it is too costly, and when heated it absorbs and gives off gases. As to the possibility of plunging the bulb of this instrument into molten metal, as brass or copper, would reply that on account of the brittleness of porcelain I do not consider it practicable. It is expected that for such purposes the porcelain bulb may be replaced by a metallic one having a higher fusion point than the molten metal of which it is desired to measure the temperature.

Replying to Mr. Lewis's question, as to the effect of different temperatures on the connecting tube, I would say that such differences of temperature have no effect upon the record, as the capillary connecting tube is only $\frac{1}{100}$ inch internal diameter, and as the compensating spring corrects for changes of temperature outside of the furnace.

In reply to Mr. Dean, as to the manner of supporting pyrometers in the furnace, I would say that the porcelain bulbs are made of a cross-section as indicated in Fig. 30. The air space is about 8 inches long and 1 inch diameter. The external diameter of bulb and stem is about $1\frac{8}{8}$ inches. The total length of bulb and stem is about 34 inches, making it possible to pass the stem of the bulb through an opening in the side of the furnace, supporting it near the cool end of the stem. It is only necessary to apply the heat to the full length of the air space of the bulb.

Answering Professor Lanza in regard to drying the air, I would say that the instrument is put together completely, and an opening is left at the recorder end, while the porcelain bulb is exposed to the full temperature of furnace. This expands and drives out the surplus of air, leaving only thoroughly dried air in the bulb.

The opening is closed while the bulb is still exposed to full heat. As an extra precaution, the bulb and connecting tube are sometimes washed out with nitrogen, which would have no detrimental influence on the metallic portions of the instrument. I hope to be able at some future time to present results of further experiments with this instrument, especially as regards its applicability to temperatures over 2,000 degrees Fahr.

No. 875.*

EFFICIENCY OF A GAS ENGINE AS MODIFIED BY POINT OF IGNITION.

BY C. V. KERR, CHICAGO, ILL.
(Member of the Society.)

IN the gas-engine laboratory of the Armour Institute of Technology there is installed for experimental purposes a four-cycle single-cylinder gas engine, built by the Fairbanks-Morse Company, and rated at 7 brake horse-power. The cylinder is $6\frac{3}{4}$ inches in diameter, the piston stroke 12 inches, the clearance about 35 per cent., and the normal speed 240 revolutions per minute. The engine is controlled by a centrifugal governor acting on the hit-and-miss principle. The ordinary poppet valve is used, and both the hot tube and the electric igniter are available.

The brake horse-power developed is measured by a form of rope brake consisting of narrow wooden cleats stapled to a thin wire tiller rope, supported by a stand resting on platform scales. The brake pulley is water cooled. The power developed in the cylinder is measured by a special gas-engine indicator, actuated by a pantograph reducing motion. The number of explosions is recorded by a box counter, operated by the gas-inlet valve rod, which secures a count of the admissions of gas. The engine speed is obtained either by speed counter or tachometer.

The quantity of gas used is measured by a wet-test gas meter, readable to 0.002 cubic foot. The heating power is determined by combustion in the Junker calorimeter. When the hot-tube igniter is in service, the meter for the calorimeter is used on the hot-tube connection, so that the amount of gas going to the cylinder may be known. A larger meter of the ordinary type

* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

serves to determine the proportions of air and gas actually used. The air was at first drawn through this meter, but later a blower was installed to force it through and deliver it to the engine at more nearly ordinary pressure.

During the spring of 1897, N. M. Loney and J. J. Wheeler made a series of tests with this plant to determine the heat efficiency of the engine from no load to full load. The mixture used was 6.6 cubic feet of air with 1 cubic foot of natural gas. The heating power of the gas, as determined on different days during the tests, varied from 811 to 867 British thermal units. The jacket water was kept at about 160 degrees Fahr. The hot-tube igniter was used, as the earlier form of electric igniter run by a battery was found unreliable. The usual form of indicator

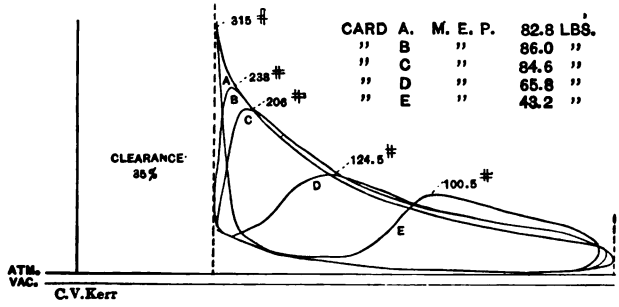


FIG. 33.—CARDS FROM 7 B.H.P. GAS ENGINE, SHOWING EFFECT OF HOT-TUBE TEMPERATURE.

card secured is shown by card *B* in Fig. 33. The indicated horse-power ranged from 3.8 to 11. The compression pressure was about 60 pounds, and the explosion pressure about 240 pounds. The heat efficiency, as fixed by the ratio of the heat equivalent of work done in the cylinder to the heating power of the gas, was nearly constant throughout the range of load at 22 per cent.

The group of cards shown in Fig. 33 was obtained from the engine when, so far as known, all variables, except the temperature of the hot tube, were kept constant. Card *A* has much to favor it from the thermodynamic standpoint. There is the desired high initial temperature, with apparently complete combustion, and the low terminal pressure following expansion. But the mean effective pressure as noted is not so great as in card *B*. The conclusion from this was verified by a test which

showed a lower heat efficiency. Card *C* has a higher mean effective pressure and is easier on the engine than card *A*.

In the upper part of Fig. 34 is shown a pair of cards from a 70 horse-power steam engine running at 264 revolutions per minute. There is a difference of 1.9 horse-power between head and crank end cards. Taking the various inertia forces into account, the resulting crank effort curves are shown in the lower part of the figure. There is now a difference of 6.0 horse-power between the out and in strokes, while the total power is

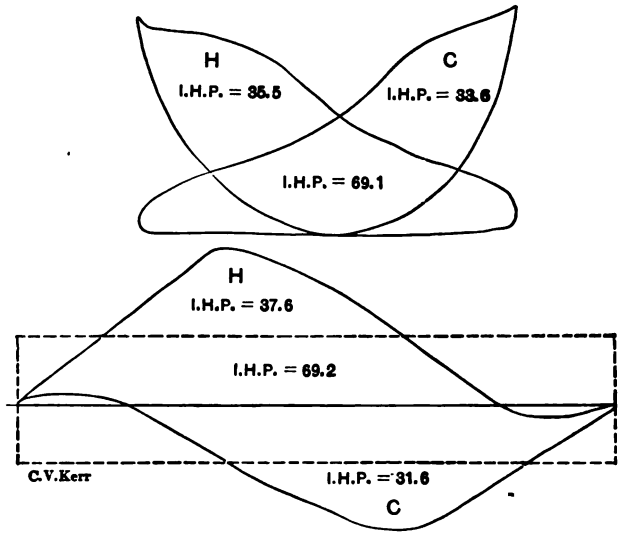


FIG. 34.—CRANK EFFORT CURVES, SHOWING EFFECT OF ANGULARITY OF CONNECTING ROD.

essentially the same. The reason for this effect seems to be due to the angularity of the connecting rod, which puts the maximum component of the thrust along the rod into tangential effort on the crank during the first half of the out stroke and during the second half of the in stroke. In the single-acting gas-engine cylinder, where the work is done on the out stroke and the charge compressed on the in stroke, this is a decided mechanical advantage. Moreover, the times of greatest piston velocity coincide with the times of greatest thrust. Heat is constantly passing through the cylinder walls into the jacket water. It is consequently important that the heat energy of the gas shall be developed at the time when the

piston is moving most rapidly and the tangential effort at the crank is greatest. In developing brake horse-power, it may be that card *C* of Fig. 33 will do better than card *B*, besides being easier on the engine.

The difficulty of securing and maintaining a temperature of hot tube giving a desired card led to fitting the engine, in the early part of the present year, with a mechanically operated electric igniter. This igniter is operated from an inclined cam on the large gear, from which motion is conveyed to a spring catch attached to an oscillating electrode. Platinum points are provided on the movable as well as on the insulated electrode, so that corrosion does not quickly affect the sparking points. As the igniter is mechanically operated, the time of separating the points is fixed for a given set of conditions, and the charge in the cylinder is always ignited at a desired piston position.

This device was so made that it can be adjusted to produce a spark in the cylinder at every second revolution for any piston position between 4½ inches before the end of the stroke and an equal distance after it. The adjustment can be made while the engine is running within limits set by the load carried. This enables the use of very early ignition after the engine reaches its normal speed.

A series of tests was therefore arranged to ascertain this point of ignition which would give the maximum heat efficiency for a given load with all variables, except point of ignition, constant. The programme of tests was carried out by L. C. Bradley, C. A. Garcelon, and C. S. Longnecker during the spring term of the present year.

A few preliminary runs settled the position of the gas valve for best air mixture at point marked 3; the temperature of jacket water at 170 degrees Fahr.; and the loads to be carried, 0, 2.5, 5.0 brake horse-power. For each load the point of ignition was made as early and as late as the engine would maintain speed. The igniter was set to pass a spark at a certain piston position, and an hour's run was made with indicator cards, readings of gas meter and explosion counter taken at frequent intervals. The sparking current for the igniter was taken from a 110-volt main. Six lamps were used in parallel to give sufficient current, and a spark coil to increase the spark. This arrangement proved entirely reliable, and the lamps gave visible evidence of the working of the igniter.

The load to be carried by the Prony brake was estimated for the standard speed, and the scale beam was maintained in even balance throughout the runs. The water used to absorb the heat developed at the brake was allowed to boil away from the inner surface of the pulley at atmospheric pressure.

About noon of each day, while running the engine, the Junker calorimeter was used to ascertain the heating power of the gas. Usually five tests were made, and the average taken as the calorific power of the gas for that day. The range of values obtained at each series of tests was always small, but there was considerable variation in average values from day to day.

The indicator diagrams of Figs. 35–43 were taken at friction load, while the point of ignition was changed from $4\frac{1}{3}\frac{2}{3}$ inches before the end of the compression stroke to 2 inches after the beginning of the expansion stroke. The heat efficiency is greatest for ignition at $(+\frac{1}{2})$, as shown by Fig. 38, while the explosion pressure is greatest for still earlier ignition, as shown by Fig. 37. The terminal compression pressures vary from 55 to 65 pounds, and the pressure at release from 29 to 54 pounds.

For a brake load of 2.5 horse-power the greatest efficiency is found again with ignition at $(+\frac{1}{2})$, while the maximum explosion pressure is found still earlier at $(+2\frac{1}{2})$. The general features of the diagrams remain the same as at the friction load. With a brake load of 5.0 horse-power, the maximum efficiency is found with ignition at the dead point; but the highest explosion pressure is for ignition at $(+2\frac{1}{2})$, and the maximum pressure is not located. A wider range of ignition could not be secured with this brake load, and a series of runs with higher brake load was not attempted.

One curious result is brought out by the curves of indicated horse-power. The mechanical efficiency of the engine tends to increase slightly as the ignition occurs later. Probably not so much energy is spent in friction at the main bearings. So far as the heat efficiences at brake and in cylinder are concerned, it is evident that ignition should never be later than at the dead point.

The time of the explosion, as measured by the interval between ignition and maximum pressure, is unexpectedly constant at 0.03 seconds for ignition before the dead point. For later ignition there is a decided tendency to increase the time of

combustion. This fact may explain why the heat efficiency drops off with the earlier ignitions, even though the explosion pressure is higher. The time of combustion being constant, the higher the pressure and temperature reached the larger the proportion of heat transmitted to the jacket water.

Such conclusions apply strictly only to the gas engine of the size and make under test, with certain conditions constant. With different proportions of gas and air, with another kind of gas, or with a less positive sparking device, quite different results might possibly be reached. But in this case the conditions were so chosen that the results were expected to show the best performance of the engine.

FIRST SERIES—FRICTION LOAD.

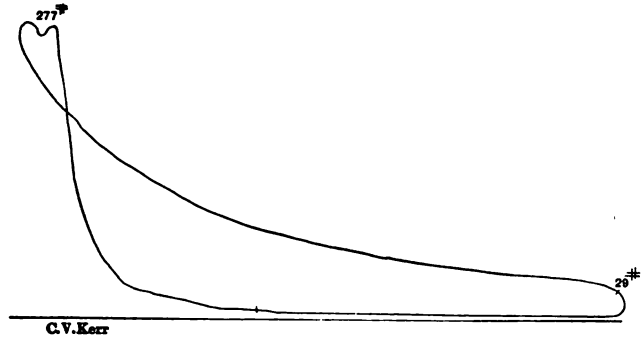


FIG. 35.—IGNITION, + $4\frac{1}{32}''$.

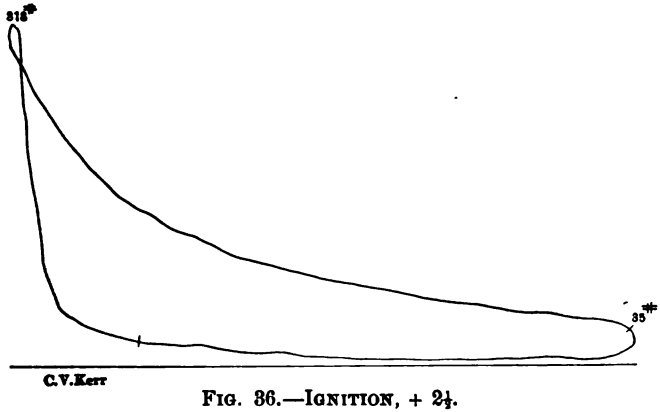


FIG. 36.—IGNITION, + $2\frac{1}{4}$.

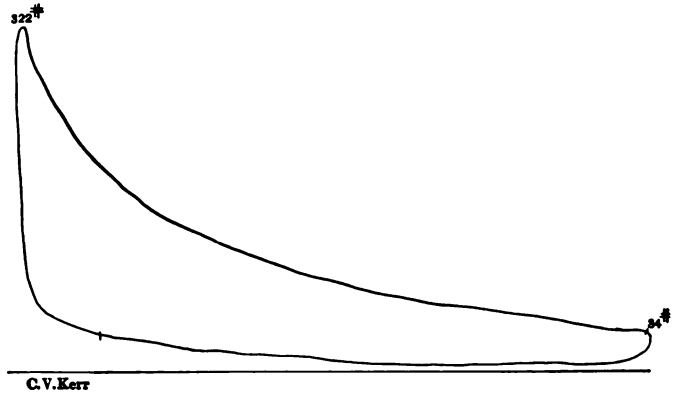


FIG. 37.—IGNITION, + 1½.

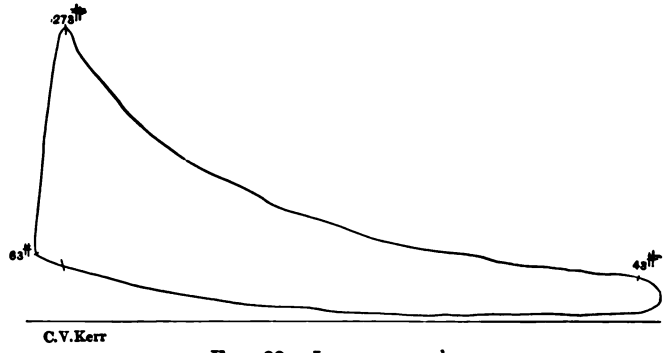


FIG. 38.—IGNITION, + ½.

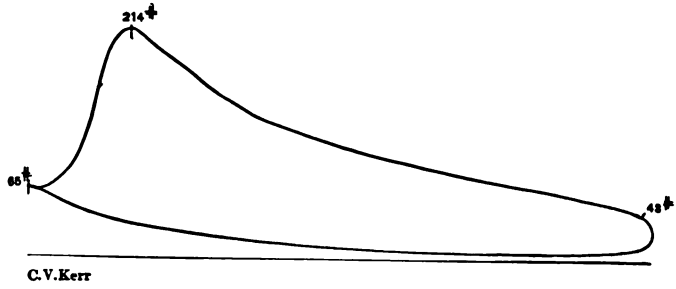


FIG. 39.—IGNITION, ± 0.

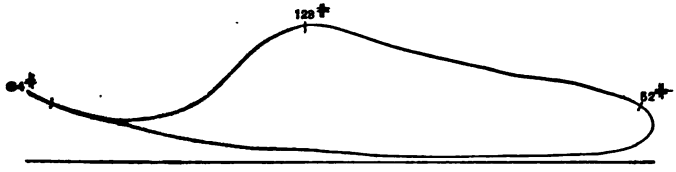


FIG. 40.—IGNITION, — ¼.

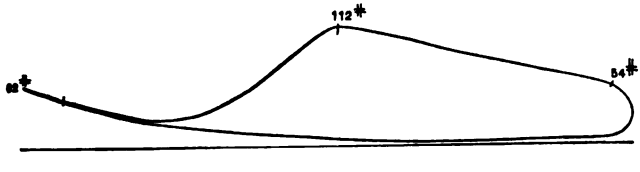


FIG. 41.—IGNITION, — 1.

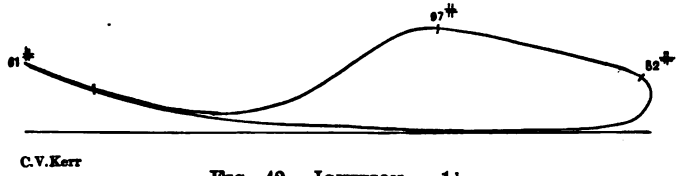


FIG. 42.—IGNITION, — 1¼.

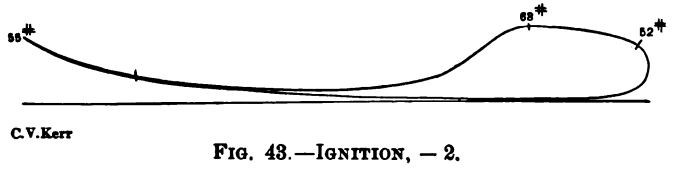


FIG. 43.—IGNITION, — 2.

SECOND SERIES—B.H.P., 2.5.

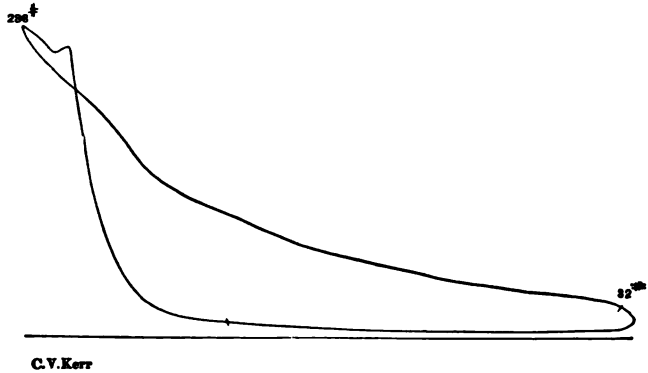


FIG. 44.—IGNITION, + 4½.

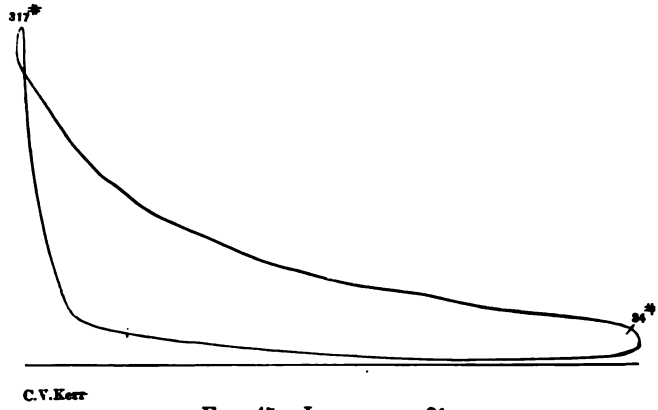


FIG. 45.—IGNITION, + 2½.

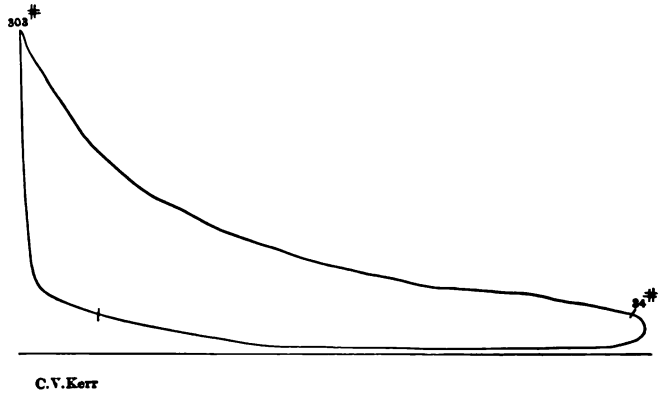


FIG. 46.—IGNITION, + 1½.

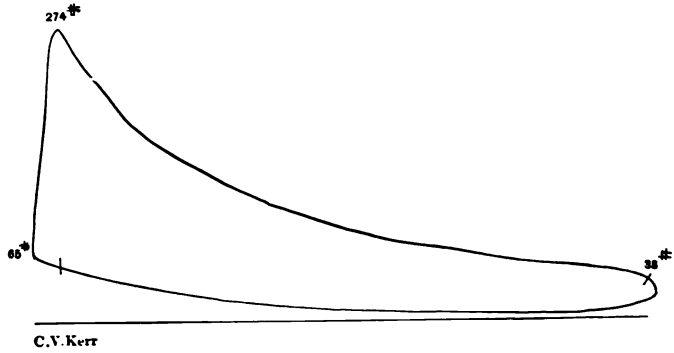


FIG. 47.—IGNITION, + ½.

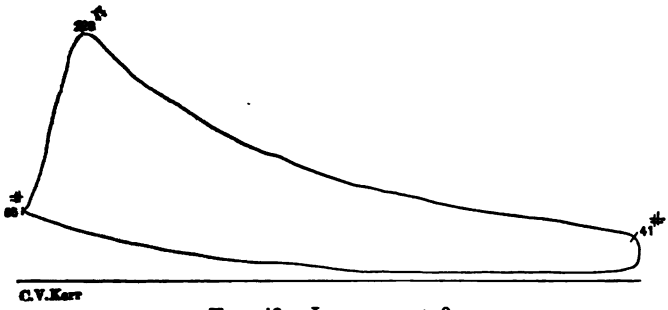


FIG. 48.—IGNITION, ± 0.

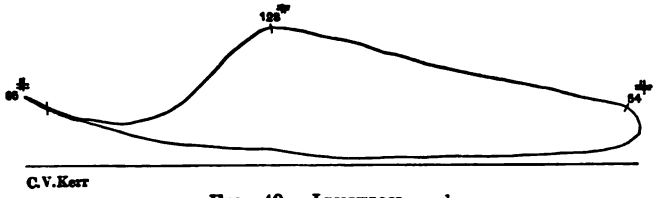


FIG. 49.—IGNITION, − ½.

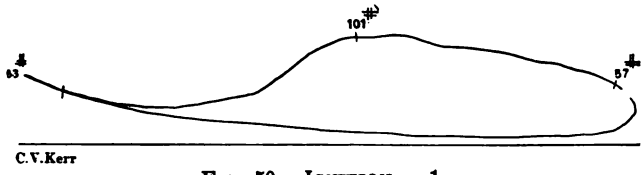


FIG. 50.—IGNITION, − 1.

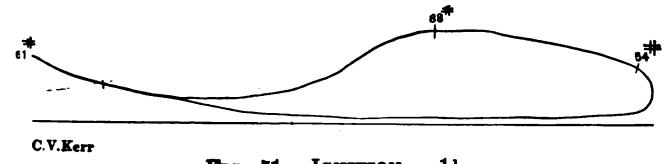


FIG. 51.—IGNITION, − 1½.

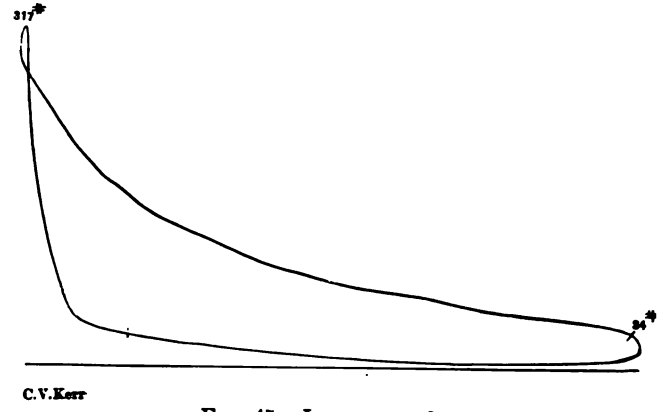


FIG. 45.—IGNITION, + 2½.

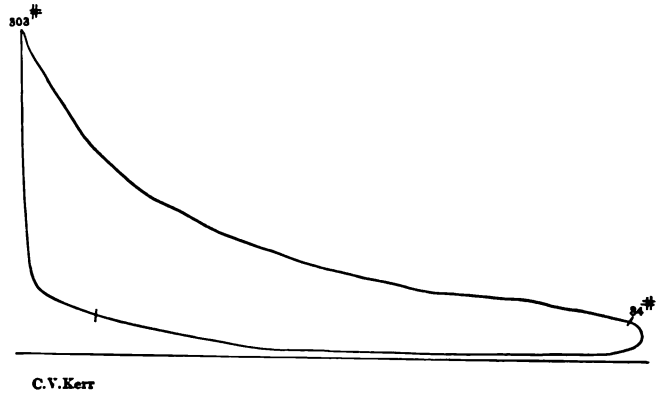


FIG. 46.—IGNITION, + 1½.

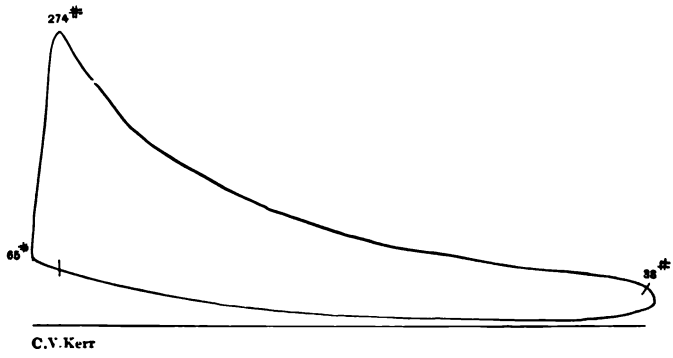


FIG. 47.—IGNITION, + ½.

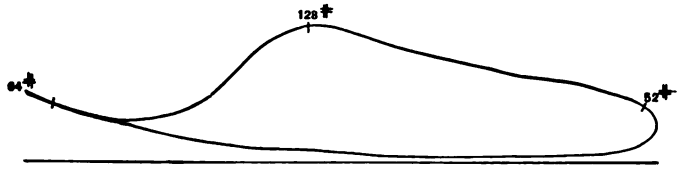


FIG. 40.—IGNITION, — ½.

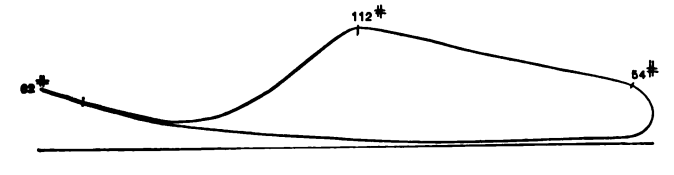


FIG. 41.—IGNITION, — 1.

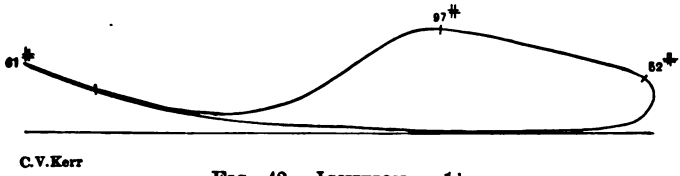


FIG. 42.—IGNITION, — 1½.

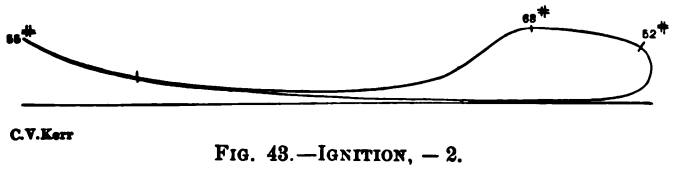


FIG. 43.—IGNITION, — 2.

SECOND SERIES—B.H.P., 2.5.

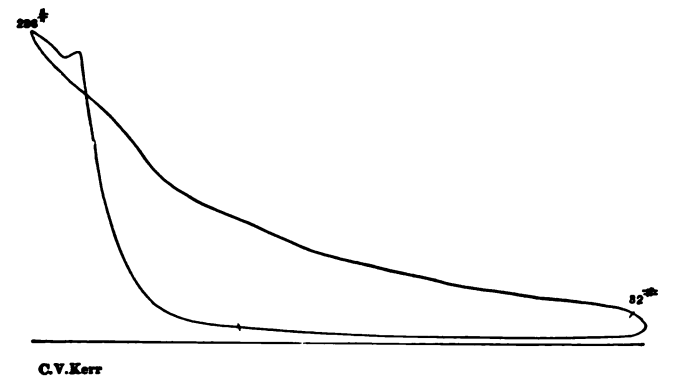


FIG. 44.—IGNITION, + 4½.

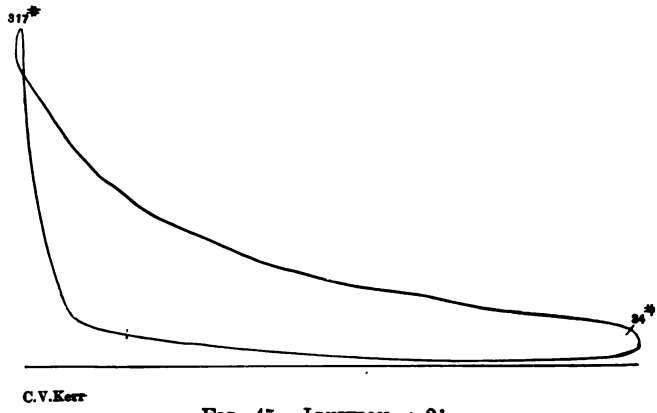


FIG. 45.—IGNITION, + 2½.

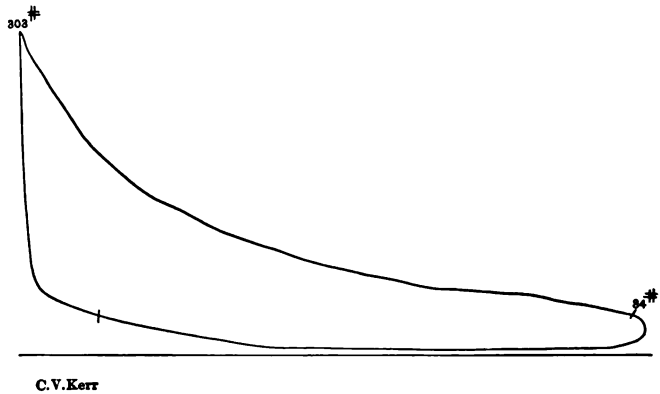


FIG. 46.—IGNITION, + 1½.

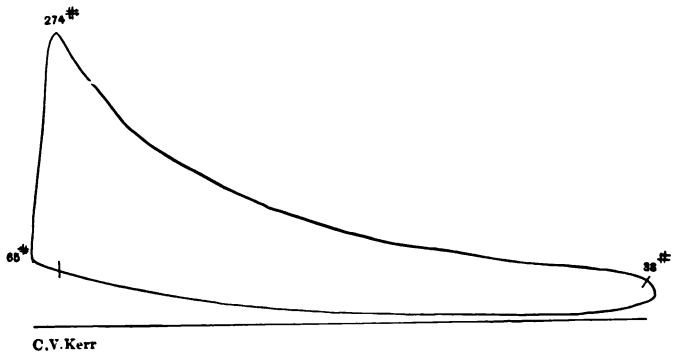


FIG. 47.—IGNITION, + ½.

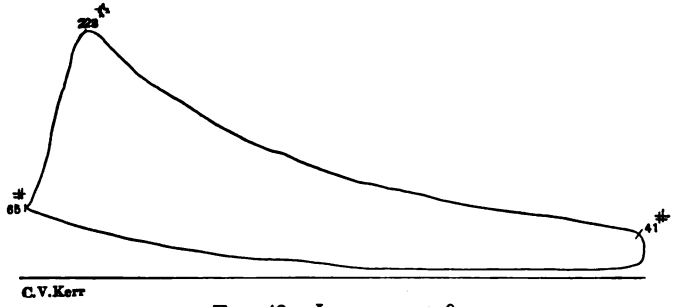


FIG. 48.—IGNITION, ± 0.

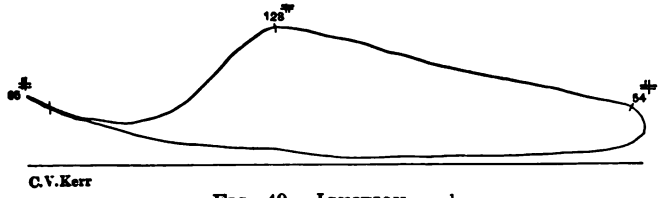


FIG. 49.—IGNITION, − ½.

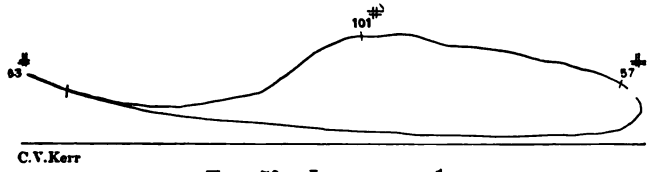


FIG. 50.—IGNITION, − 1.

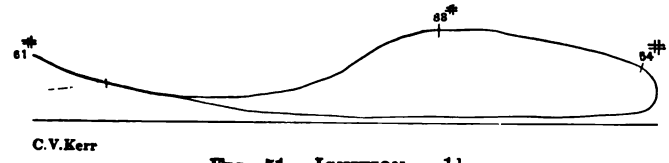


FIG. 51.—IGNITION, − 1½.

THIRD SERIES—B.H.P., 5.0.

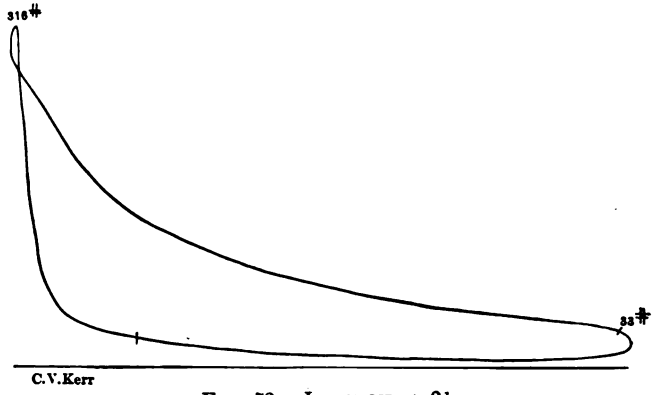


FIG. 52.—IGNITION, + 2½.

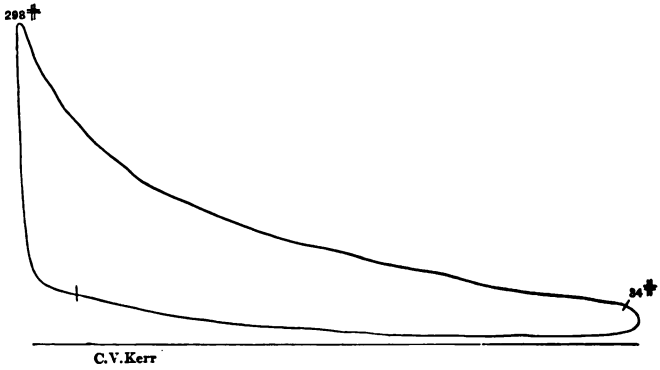


FIG. 53.—IGNITION, + 1½.

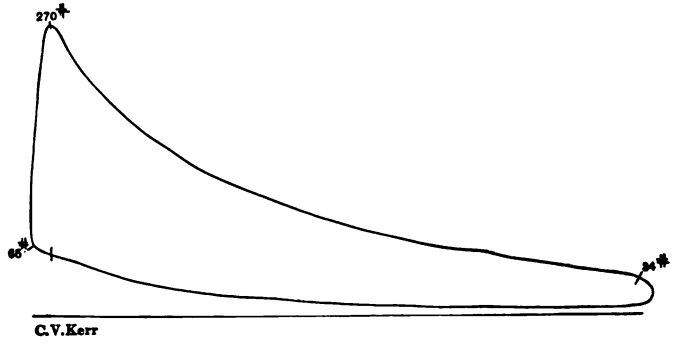


FIG. 54.—IGNITION, + ½.

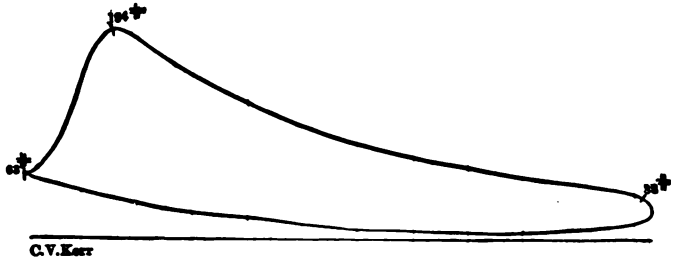


FIG. 55.—IGNITION, ± 0.

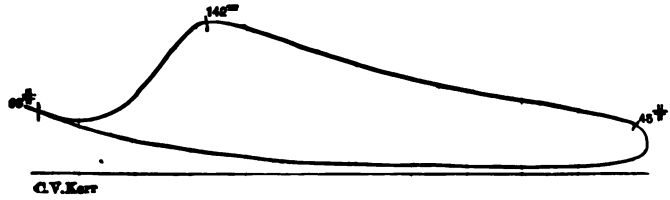


FIG. 56.—IGNITION, $-\frac{1}{2}$.

SUMMARY OF TESTS.

Point of Ignition. Inches.	Length of Run. Min.	Cu. Ft. Gas per Hour.	Explosions per Minute.	Engine Speed R. P. M.	Horse Power.		Average Friction H. P.	B.T.U. in Gas.	Heat Efficiency.	
					Indicated	Brake			In Cylinder.	At Brake.
$+4\frac{1}{2}$	60	65.72	44.3	238	2.63	0		893	0.114	0
$+2\frac{1}{2}$	30	54.24	34 6	"	2.82	0		"	0.148	0
$+1\frac{1}{2}$	60	43.52	27.3	"	2.63	0		"	0.172	0
$+\frac{1}{2}$	60	40.08	25.0	"	2.63	0		"	0.187	0
±0	60	40.47	25.0	"	2.31	0	2.56	"	0.163	0
$-\frac{1}{2}$	60	65.83	41.1	"	2.83	0		"	0.123	0
−1	60	74.45	50.3	"	2.54	0		"	0.097	0
$-1\frac{1}{2}$	40	85.02	54.4	"	2.41	0		"	0.081	0
−2	60	115.26	83.7	"	2.21	0		"	0.055	0
$+4\frac{1}{2}$	60	106.82	79.2	"	5.08	2.5		938.5	0.128	0.063
$+2\frac{1}{2}$	60	83.23	56.7	"	4.73	"		899.2	0.160	0.085
$+1\frac{1}{2}$	60	71.95	50.1	"	4.67	"		938.5	0.176	0.095
$+\frac{1}{2}$	60	71.50	47.3	"	4.73	"	2.08	899.5	0.186	0.098
±0	60	66.75	45.0	"	4.44	"		938.5	0.181	0.102
$-\frac{1}{2}$	60	97.18	68.6	"	4.35	"		977.0	0.116	0.067
−1	60	118.42	86.7	"	4.14	"		955.0	0.098	0.056
$-1\frac{1}{2}$	60	147.60	109.3	"	4.47	"		955.0	0.081	0.045
$+2\frac{1}{2}$	60	131.78	96.7	"	7.96	5.0		899	0.171	0.108
$+1\frac{1}{2}$	60	120.44	88.8	"	7.46	"		"	0.175	0.118
$+\frac{1}{2}$	60	108.21	75.6	"	7.24	"	2.31	"	0.189	0.130
±0	60	105.25	82.0	"	7.33	"		"	0.197	0.134
$-\frac{1}{2}$	60	159.73	108.6	"	6.56	"		"	0.107	0.082

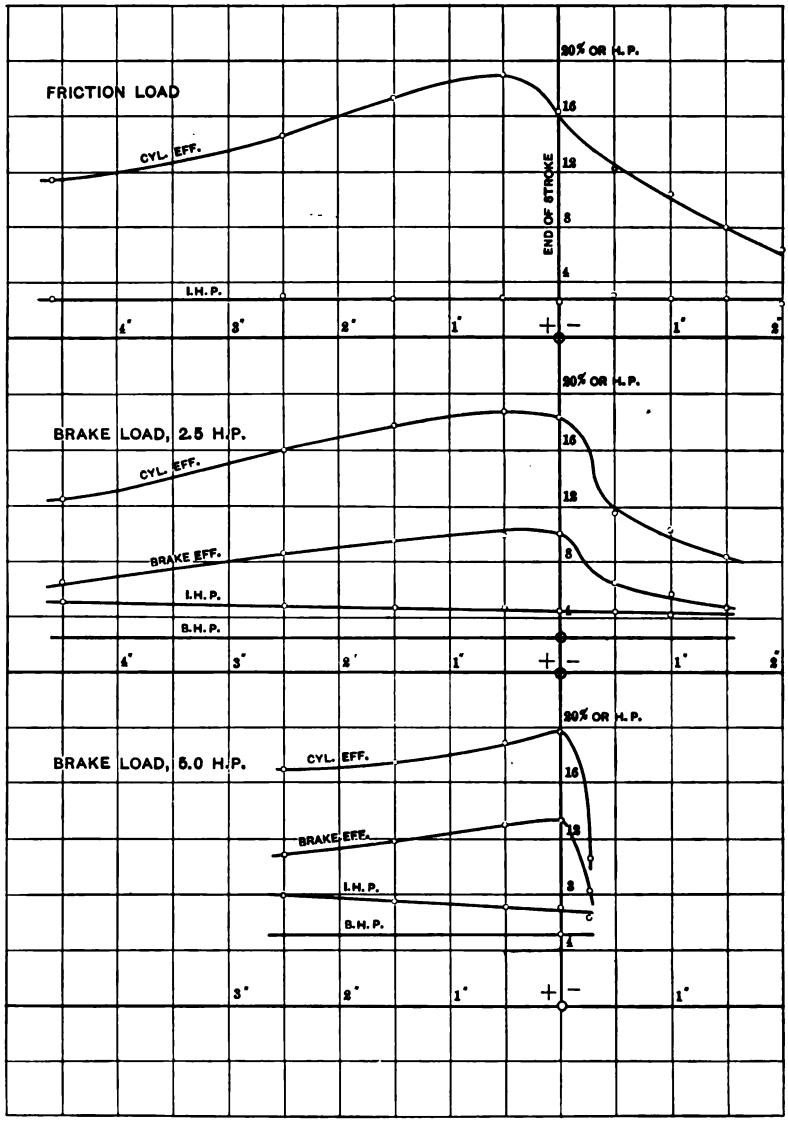
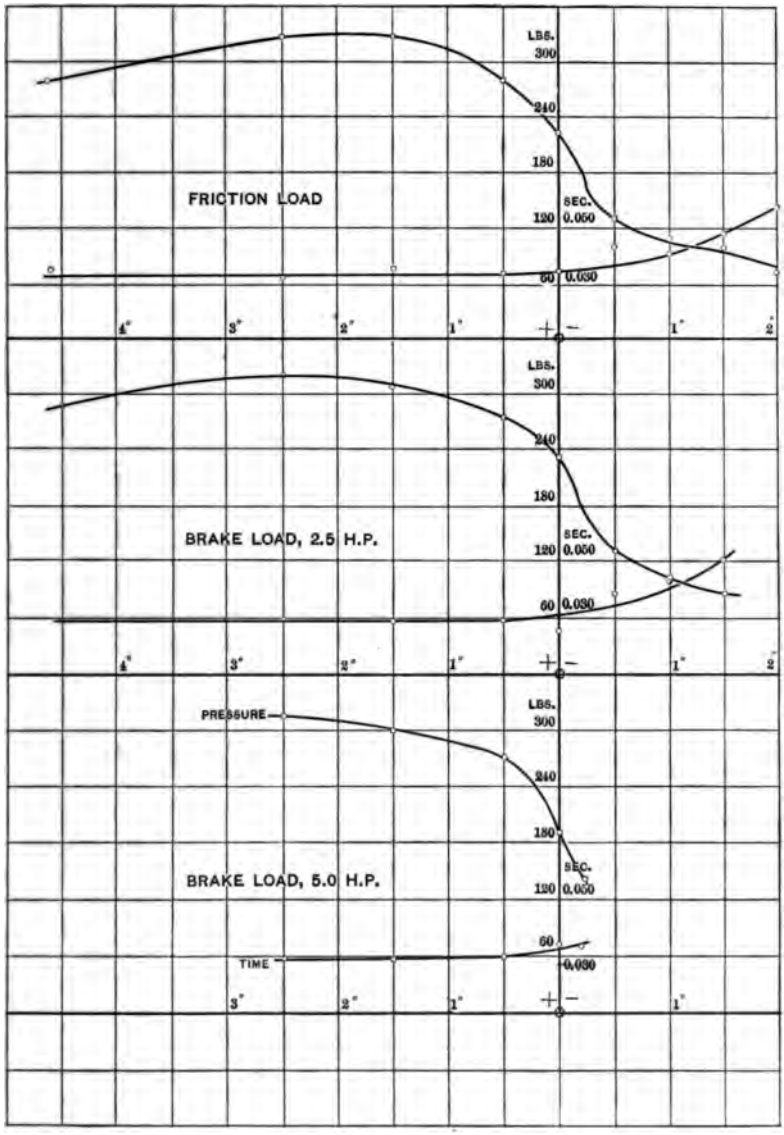


FIG. 57.—SUMMARY OF RESULTS.



C.V.Kerr

FIG. 58.—PRESSURE AND TIME OF EXPLOSION.

DISCUSSION.

Prof. Wm. T. Magruder.—This paper presents a very elegant and refined proof of the rule of practice common among gas-engine men that, with electric ignition, the engine should "fire" when the crank is about 15 degrees below the dead centre, in order that the best results may be obtained and the engine shall give the least "kick" when running. With zero and 2.5 brake horse-power, the author finds that "the greatest efficiency is found when the point of ignition is $\frac{1}{8}$ inch before the end of the compression stroke," and "at the dead point" for 5 brake horse-power. The former corresponds to an angle of 23 degrees 33 minutes, while 15 degrees corresponds to $\frac{1}{8}$ inch before the end of the compression stroke. It is thought that, if similar series of observations had been made with ignition at $\frac{1}{8}$ inch, slightly better results would have been secured. Otherwise, the results presented would indicate that the time of ignition should be delayed with increase of load. It is to be borne in mind that these experiments were made on a non-scavenging engine, or one which, when it misses a charge, instead of scavenging its cylinder by sucking in fresh air and exhausting the diluted burnt gases, leaves the exhaust valve open and sucks in and exhausts burnt gases. If the experiments had been performed on a scavenging engine, the first diagram indicated after a missed charge would have been more like Figs. 36, 45, and 52.

Assuming that "the summary of tests" in the paper is accurate, the figures illustrate that the friction of a gas engine is not necessarily constant, nor yet is it a function of the horse-power; but rather that the friction increases with the earliness of ignition, and that the maximum indicated horse-power for a given brake horse-power may be as much as 21 per cent. greater than the minimum. Fortunately for the user, the heat efficiencies do not vary much so long as the point of ignition is within a range of 25 degrees before the end of compression stroke.

Mr. C. E. Sargent.—While the intention of this paper seems to be the proper location of the point of ignition relative to the piston, for the maximum efficiency under different loads, the results obtained are exactly what we would expect from an engine fitted with a hit-and-miss governor. The conditions are constant for any location of the point of ignition through all the series of tests, and the efficiency curves should be as they are, practically parallel within the capacity of the engine. Of course, with the

load, we have more impulses per minute than with no load; but the mean effective pressure for each impulse should vary but little, and the deductions show that, whether we have 25 or 75 explosions per minute for a maximum efficiency, the ignition should take place when the piston is $\frac{1}{2}$ inch before the end of the compression stroke.

In order to make these data more accessible, would it not have been better to have given the crank position in degrees, making it thus applicable for any length of stroke? We see from the diagram that, for maximum efficiency, the ignition line leans towards the crank, and, instead of locating the point of ignition—which would vary with the ratio of gas and air, piston speed, and other conditions—would not a determination of the proper angle of the ignition line with the vertical locate the form of diagram for maximum efficiency, no matter how the conditions changed?

In the test presented to us, we have a constant mixture of gas and air, a constant compression, a constant piston speed, and a constant ratio of volume to the confining surface. Now, as the *time* during which the pressure after ignition remains higher than the pressure before ignition is but a few seconds' duration, it is evident that, with a higher piston speed, the angle of the ignition line would be greater if the point of ignition were constant, so that, in order to maintain a uniform angle determined for maximum efficiency, it would be necessary to change the point of ignition as the piston speed varied, so that a determination of the angle in question would be of more value to us than the location of the ignition point.

As the amount of heat transmitted to the cylinder walls depends upon the difference in temperature between the gases and the metal which confines them, it would seem that a late ignition would increase the efficiency, as the increase in velocity of the piston would prevent the high initial temperature, and less heat would be lost by radiation. Yet, on the other hand, as the piston moves away from the burning gases, so that the difference in temperature is less, the surface of radiation is greater.

Professor Kerr's experiments show us that for a constant piston speed, compression, and gas and air ratio, there is a happy medium, where a certain point of ignition will produce a maximum efficiency, and that the line of ignition—or, to use a military term, the "firing line"—produces a certain angle with the vertical. Now, if this angle is once determined, it ought to be easy to main-

tain the same by changing the point of ignition as the piston speed or mixture changes.

As the engine tested had a hit-and-miss governor, compression is practically constant; but with an engine governing by varying the mean effective pressure, the compression would decrease with the load, and, on account of the molecules being farther apart and the mixture more diluted with the constant volume of clearance gases, the inflammation would be slower, the angle of the firing line greater, and there would be a corresponding drop in efficiency; so that, to maintain a maximum efficiency through all changes of load, the ignition point should be advanced as the load is decreased or as the mixture is cut off. Fig. 107,* in Paper No. 879, is a diagram from an engine which varies the point of ignition with the load, and shows very clearly how the angle of the firing or of the ignition line may be practically constant for any variation in load.

Where the point of ignition remains constant as the load gets lighter, the inflammation gets slower, and the maximum pressure is not attained until the piston approaches the middle of the stroke. (See Fig. 101, Paper No. 879.*) Under these conditions the firing line is nearly at right angles to the vertical, and is one of the causes of the ordinary engine's low efficiency at light loads.

Prof. C. V. Kerr.†—While referring to the opening sentences of Professor Magruder and Mr. Sargent in discussion on this paper, I must confess to having at one time, and that not far distant, entertained the notion that a gas-engine card like Fig. 105, with its high initial and low terminal pressures, should give higher heat efficiency than one like Fig. 106,* with lower initial and higher terminal pressures. The formulas for efficiency in thermodynamics certainly favor it. And the text-books, with their varying degrees of intimacy in mixture of theory and practice, give no explanation of the fact that the preferred gas-engine card is given a "firing line" inclined toward the crank, except, perhaps, that such a card is easier on the crank and main bearings.

The old-fashioned hot-tube igniter cannot be relied upon to maintain a given card in a series long enough to determine its

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* "A New Principle in Gas-engine Design," by C. E. Sargent, in current volume; read at the New York meeting.

† Author's closure, under the Rules.

efficiency. Only the advent of the adjustable electric igniter enables the time required for combustion and the efficiency depending upon a wide range of points of ignition to be determined. Now that the card with the inclined firing line is known to be more efficient under a given set of conditions than the thermodynamic ideal, I explain to myself that the heat potential of the high initial pressure forces a larger percentage of the energy developed through the cylinder walls into the jacket water than does that of the inclined firing line, while the latter develops energy at a time when a larger component is available to produce rotation effort at the crank pin.

The experiments decribed here, made with a practically constant compression, speed, and mixture of natural gas with air, might not hold true as to the angular movement of the crank during combustion if another compression pressure had been used, and an artificial fuel or illuminating gas, with varying proportions of air. Here a statement of results in terms of the inconvenient crank angle, instead of the piston position, would not be a safe guide for other conditions. The angle between the firing line and the vertical, which is here from 5 to 6 degrees, is probably a safer guide by far. The very best guide is a series of tests similar to these for the conditions assumed or imposed.

More may be learned from the indicated horse-power and brake horse-power lines in Fig. 57 than from the average friction horse-power in the "summary of results." The former show a tendency to higher mechanical efficiency for later ignition, especially for the heavier loads.

No. 876.*

THE STEAM TURBINE: THE STEAM ENGINE OF MAXIMUM SIMPLICITY AND OF HIGHEST THERMAL EFFICIENCY.

BY ROBERT H. THURSTON.

(Member of the Society.)

THE Steam Engine of Maximum Simplicity and of Ideal Thermal Efficiency would presumably be defined, by one familiar with the general principles of science—even if entirely ignorant of its applications of contemporary date in the heat-motors, mechanically—as a machine having a minimum number of moving parts and thermodynamically free from other wastes than those of the ideal thermodynamic machine. Such a machine has never been produced, and it is not to be expected that it will ever be constructed in perfection. Yet the close of the nineteenth century sees a remarkably close approximation to this ideal; and that, curiously enough, by reversion to an ancient type and by the reproduction, in refined form and proportions, of the "Greek idea of the steam engine," as illustrated by Hero in his "Pneumatica," 120 B.C., and in better type, though no better form, by Branca, in his "Machine deverse," of 1629.†

The ideal construction is certainly reached in a machine in which there exists but a single moving element; and the ideal thermodynamic machine is approximated in a motor in which adiabatic expansion is secured, and friction and heat waste may be made sources of comparatively small loss. The elements of waste, conduction, and radiation, and incomplete expansion, are probably capable of large reduction, with improved construction and continued experience in the apportionment of the

* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† "History of the Growth of the Steam Engine; International Series." New York, London, Leipzig, and Paris, 1878. "Manual of the Steam Engine," vol. i., chap. 1. New York and London, 1890-1900.

apparatus to its work. The main purpose of this discussion is to summarize the work of the steam turbine to date—as well as may be—and to study the sources of loss as it is now constructed and operated, and to deduce, if possible, the principles involved in its correct design, construction, and operation—meantime bringing out into relief facts indicating the essential importance of employing superheated steam in a machine in which it has seemingly no other than thermodynamic value, and of the use of condensation to enable the engineer to evade a loss

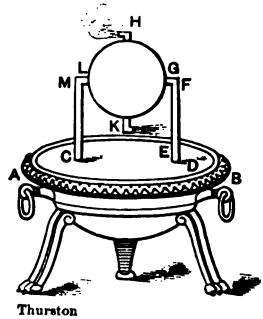
FIG. 59.—THE FIRST STEAM TURBINE.

and accomplish a purpose which have no counterparts in the case of the piston engine.

The Steam Turbine—known as a "reaction wheel" to Hero (120 B.C.) and the Greeks, and possibly long before the Christian era—proposed by Branca in 1629, in the type-form familiar to us in the hydraulic motors of the Pelton class and the steam turbine of the Laval form, has only recently come to be considered seriously by the engineer as a practicable form of heat-motor. This was not because its principles and its ideal efficiency were not known to him; for the principles of design, construction, and action are precisely the same as those of the

hydraulic motors, and have been developed with the greatest elaboration by Weisbach and other early writers of our time, and have been applied in construction by the engineers of every civilized nation. It was not because no attempts had been made to utilize this class of motors; for, from time to time, ever since Branca, and especially within the past century, steam, as well as hydraulic, turbines have been built and experimentally used.*

More than half a century ago, a steam turbine of the Hero form was built in Syracuse, by Wm. Avery, which, with its comparatively large scale of construction, fairly well-proportioned arms, and generally excellent design, was found to give, as then reported, practically the same economy in operation as the or-



Thurston

FIG. 60.—HERO'S ENGINE, B.C. 120.

dinary steam engine of the time of similar power. Within the last twenty-five years, both the Hero and the Branca forms of turbine have been extensively introduced into the United States, and without attracting attention, either of the public or even of engineers, by the constructors of dairy machinery in their "cream separators" or "centrifugals," making from 6 to 8 thousand revolutions per minute or more in small sizes, and where no other direct-acting motor is practicable. The result was an astonishing efficiency in many cases of good design; and the Branca form, particularly, exhibits such satisfactory qualities,

* One of the earliest recollections of the writer was the construction of a Branca turbine by Messrs. Thurston, Green & Co., at Providence, R. I., on the order of an inventor named Schmidt, which was intended to develop a very considerable amount of power. In consequence, however, of the ignorance of its inventor and designer, its proportions and forms of details were altogether incorrect, and the machine as constructed was naturally a failure.

as constructed by Laval for this use, as to make it a permanent and standard addition to our list of prime movers. Many inventors have attempted its perfection during the last years of the nineteenth century, and its efficiency has been brought up by Parsons, Laval, and others of the more successful among them, to a very satisfactory figure. Thus it has come to compete seriously with the reciprocating engine in many directions in which high speed of rotation is allowable or desirable; although usually the steam turbine has a "best speed" as much above the highest desirable speeds of rotation of even fast-running machinery as that of the ordinary steam engine is below; and

FIG. 61.—BRANCA'S STEAM ENGINE, A.D. 1629.

[From "History of Growth of Steam Engine," p. 17.]

"speeding down" is found as objectionable in many cases as "speeding up." The facts are, that the machine is as simple in construction as the reciprocating steam engine—especially in its multiple-cylinder forms—is complex; that it is comparatively simple in principle and inexpensive in construction, and that it may attain great economy in the use of steam and of fuel.

Rankine states that Mr. Ruthven brought a Hero turbine into use "to a limited extent" many years ago in Scotland, and that Mr. Wm. Gorman constructed an inward-flow turbine, which was set up and operated in the Glasgow sawmill, attaining as high an efficiency as "the ordinary high-pressure engine"—presumably meaning a non-condensing engine.*

* "The Steam Engine," p. 538; 14th ed., 1897.

The later "compound" steam turbine has recently been extensively employed in the operation of dynamo-electric machinery. It consists of two sets of parallel-flow turbines set, in twin series, on one shaft on either side the induction-pipe, thus balancing. The passages are gradually enlarged as the volume of the steam increases with its progressive expansion. The Parsons is the best-known form.

The turbines thus alternate with their guide blades, and both the vanes and the blades are carefully proportioned and set to secure maximum attainable efficiency at the proposed speed of rotation, their pitches and depths being suitably varied.

The computed efficiency, without allowances for wastes, is about 87 per cent. The actual consumption of steam is found to be 16 to 26 pounds per electrical horse-power produced and per hour, as steam pressures rise from sixty or eighty pounds by gauge upward to several hundred. The speed of rotation ranges from 2,000 or 5,000 revolutions per minute upward, according to size and steam pressure; 15,000 and 20,000 being common speeds for the smallest sizes.

Dow's turbine is an inward-flow wheel with concentric sets of guides and vanes in series, and is said to have attained 35,000 revolutions per minute, working regularly at 25,000, consuming 45 pounds of steam per horse-power per hour. Only the most perfect construction is admissible in any turbine.

The theory of this type of machine is that familiar to the hydraulic engineer, and the speeds of orifice for maximum efficiency are well known to be infinite in the Hero class of turbine, and approximately one-half the final velocity of flow in the guide-blade turbine. Since these speeds are impracticable, a certain loss of energy is thus inevitable. In compensation for this loss, in the steam turbine, is the fact that it is not subject to that fluctuation of temperature of parts exposed to contact with the steam which results in large wastes by cylinder-condensation in the common forms of steam engine. A gain of from 25 to 50 per cent., as compared with the latter, in this way, is to be counted upon.

The Dow turbine, as built for work in connection with the Howell torpedo, gives an average of about 11 horse-power in coming up to speed in regular working, at 60 pounds steam pressure, and weighs from 100 to 150 pounds, or not far from 13

pounds per horse-power.* Its fly-wheel rim attains a speed of nearly 7 miles a minute at 10,000 revolutions per minute. The designer estimates its power, at 150 pounds steam pressure and the same speed, at 40 horse-power, or one horse-power to 3.75 pounds weight, and states that this may be still further reduced to the extraordinary minimum of 2½ pounds weight per horse-power, a figure within the estimated allowable maximum for use in aëronautic work.

The steam turbine of Parsons (1884) is an engine consisting of two series of cylindrical turbines, arranged symmetrically, right and left of the central steam inlet; the exhaust taking place from the two ends. In this manner, a balance is obtained, and the bearings are relieved of end pressure. Oil is forced through the bearings by a pump. This engine has driven a torpedo boat 100 feet long and of 44½ tons displacement at the rate of 32¾ knots, developing 2,100 horse-power with machinery weighing, with water in the boilers, 22 tons, thus producing 100 horse-power per ton and 50 per ton of displacement.

Such engines have been successfully employed in driving electric machinery and in "spinning" the "fly" of the Howell torpedo. For alternating electric currents, this system possesses the peculiar advantage of permitting a "dynamo" to be employed having but two poles. It may be readily driven continuously at speeds exceeding 10,000 revolutions per minute, and, like the Dow turbine, has been driven at 20,000 and upward. With the lower speeds of revolution usual with ordinary engines, the number of poles required generally approximates the quotient 120 times periodicity divided by speed of engine, if directly connected.†

The best of these machines have demanded from 16 pounds of steam per horse-power per hour, upward, according to pressure employed and amount of superheating. It may be assumed that they will require not far from the weight, for large powers,

$$W = \frac{a}{\sqrt{p_1}};$$

where p_1 lies between 50 and 200 pounds per square inch by gauge, and the apparatus is operated under favorable conditions; the value of a lying between 200 and 300 with dry steam.

* "Manual of the Steam Engine," vol. ii., pp. 62, 225.

† *Electrical World*, April 18, 1891.

In the United States, the substitution of the Dow turbine for the systems previously in use, for spinning torpedoes, has brought down the weight and volume of machinery from the earlier minimum of 360 pounds and three cubic feet per machine to 55 pounds and one cubic foot.

In the steam turbine, either the common direct-flow turbine or a "scroll wheel" of the Whitelaw type—in which the reaction of the current develops an amount of energy which approaches the ideal maximum as the speed of rotation and of the discharge orifices increases—within practical limits, the design, as of nearly all peculiar forms of engine, is a subject of no great difficulty, all the principles which have been given applying to them as to ordinary engines. This designing involves merely the determination, first, of the maximum speed of rotation practicable, and next, the diameter permissible. These points settled, the wheel is given a general form such as will least affect efficiency by its friction resistances, either on its journals or in the air, and a size of orifice such as will discharge the required weight and volume of steam at the pressure fixed upon. In some cases, compounding has been resorted to, to reduce the speed of rotation for high efficiency, with good results. Properly designed and operated, these machines should give quite as high efficiency as the small engines which they are intended to compete with.

The ideal efficiency of the reaction wheels is, as shown by Rankine,*

$$E = \frac{2ar}{\sqrt{2gh}\left(\frac{ar}{\sqrt{2gh}} + \sqrt{1 + \frac{a^2 r^2}{2gh}}\right)};$$

where a is the angular velocity, r the radius to the orbit of the orifice, and h is the height due the velocity of outflow of the fluid, and E approaches unity as the value of ar approximates infinity. At a speed of orifice equal to that of outflow of similar steam from a fixed orifice, the efficiency is about 0.7.

It is an interesting and curious fact that this earliest of all steam engines, antedating James Watt nearly 2,000 years, should have a higher ideal efficiency than the best of modern engines.

* "Steam Engine," p. 197, § 176.

A common speed is that which makes the velocity of orifice equal $v = \sqrt{2gh}$, where h is the height due the work of expansion to zero-pressure.

The speeds of the steam turbines thus enormously exceed those of any form of engine with reciprocating piston, or even of the so-called rotary engines. The three- and four-cylinder engines of the Brotherhood type, in which the several cylinders are usually grouped radially about a common crank and shaft, often exceed 1,000 revolutions per minute and have been driven, experimentally, above 2,500; but the steam turbine of Parsons makes 10,000 and even 20,000 revolutions and the Dow turbine is reputed to have attained 25,000, in small sizes.*

Advantages claimed for the steam turbine of good construction, as stated by Mr. Parsons, are, for the marine engine:

1. Increased speed.
2. Increased economy of steam.
3. Increased carrying power of vessel.
4. Increased facilities for navigating shallow waters.
5. Increased stability of vessel.
6. Increased safety to machinery for war purposes.
7. Reduced weight of machinery.
8. Reduced space occupied by machinery.
9. Reduced initial cost.
10. Reduced cost of attendance on machinery.
11. Diminished cost of upkeep of machinery.
12. Largely reduced vibration.
13. Reduced size and weight of screw propellers and shafting.

Professor Ewing concludes:

"The application of steam turbines to torpedo boats, destroyers, gunboats, and cruisers, is to be anticipated from their unique capacity for developing great power and high speed with light and compact machinery. Apart, however, from these uses, it appears to me highly probable that they will in time be adopted in the mercantile marine. The conditions in a fast passenger steamer are favorable to the economical application of steam turbines, and in such steamers the smoothness of their running will be a strong recommendation. I see no drawback

* *Trans. A. S. M. E.*, vol. x., 1889, p. 681. For much of the above and other data relating to the high-speed motors, see "Manual of the Steam Engine," vol. i., pp. 237–241; vol. ii., pp. 158–160.

likely to detract from the advantages which they plainly possess."

Experience already had with this motor leads Mr. Parsons to assert:

"The application of the steam-turbine principle to fast ships in general, including passenger vessels, Atlantic liners, and ships of war, would appear to present no special difficulties. It may be said, generally speaking, that the larger the scale on which the engines are made, the simpler is the construction, the higher the steam efficiency, and the lower the speed of rotation."

The Rotary Steam Engine, the "steam wheel," as Watt called his patented form of this machine, does not seem to promise rivalry with either the reciprocating engine or the turbine. It is apparently incapable of securing the essential requisites of successful application in such extent and perfection as to give it place in the general market for prime movers. It is almost invariably subject, with continued use, to serious leakage, a waste which may be made practically insensible in either of the other machines; it can rarely, if ever, be made to regulate with satisfactory certainty and exactness; it seldom, if ever, gives entirely satisfactory expansion of steam, and it has not yet been found practicable to unite the elements of economical operation with those of precise adaptation to the work, as illustrated by the arrangement, in the reciprocating engine, in which the governor determines that adjustment by regulating the ratio of expansion.

The best rotary-engine work with which the writer is acquainted is that of the Noteman engine, of 20 years ago nearly, in which, when developing 12.5 horse-power on the brake, 15 were measured by the indicator; the speed being 350 revolutions per minute and the steam pressure 60 to 80 pounds; the ratio of expansion was very nearly 2, as shown on the diagram, but more nearly 1.5 in fact, clearances being considered. It was subject to a loss of about 25 per cent. through internal condensation—a small figure, however, for the size of engine. A variety of other rotary engines, tested by the writer or the work of which has been reported to him, have demanded, on the average, not less than three times as much steam; this engine consuming 43 and the others about 156 pounds per horse-power hour; the latter, however, not being considered a very

extravagant record for reciprocating engines of minimum power. The most inefficient of the rotaries demanded about 400 pounds per horse-power hour.

This class of engines, as a rule, if not invariably, is restricted, by its complication of valve-gear and the system of movable abutments within its cylinder, to comparatively low speeds of rotation, the turbine being the standard taken. The reciprocating engine can usually compete with it.

The Steam Turbine is, in essence, economical through its simplicity and the directness which distinguishes its method of thermodynamic energy-conversion. It is subject to small loss of mechanical efficiency through friction of journals, it having but a single pair of rubbing parts, bearings of small diameter although of enormous speed of revolution, and it is entirely free from the great source of waste in the reciprocating engine, that internal variation of temperature of metal-surfaces which, ranging from the temperature of prime steam to that of the exhaust, nearly, produces wastes amounting to from 10 per cent. to sometimes 50 and more of the heat, steam, and fuel supplied. In the steam turbine, the internal surfaces, while it is in steady motion, are, in all parts, at a constant temperature, and that is the temperature, practically, of the steam in contact with the element of surface. Its only thermal loss is by conduction and radiation, and that may be made very small. Its thermodynamic losses are due, as in other steam engines, to incomplete expansion within the wheel and discharge of the fluid with considerable energy of mechanical motion through malproportion, maladjustment, or lack of adaptation of the speed of discharging orifice to the velocity of the expanding, rejected fluid in such manner as to reduce its velocity of rejection, into the air or the condenser, to a minimum.

It is, however, subject to one form of loss which does not seem to have been generally, if at all, recognized, and one which may prove to be serious, partly in its reduction of efficiency and largely in its reduction of power, particularly of small turbines. This is the friction of water or of moisture-laden steam within the passages of the turbine and, especially, between the turbine and casing, either by direct obstruction, where a film, a thread, or a mass of water lies in contact with both wheel and casing, or, indirectly, as when water drips or flows, from comparative quiescence, on the casing to take up

high velocity and large amounts of energy, by riding on the wheel.

The number of steam turbines brought out by inventors in recent years is very large, although the opportunity for radical improvement, or for original invention, in its main features of construction is small. All belong to either the Hero type of 2,000 years ago or to the Branca type of 1629.* In all cases, the principle is precisely the same, so far as the action of the steam is concerned, and in the thermodynamic operation of production of dynamic from thermal energy; the differences lie in the devices employed for steam supply, for reducing speeds of rotation of the driven shaft, and for regulation and adjustment of power to load. The literature of the subject is not extensive, and, in fact, the simplicity of the principles and of the practice in this case permits comparatively little opportunity for extensive discussion of either.† The number of patents, on minor and usually unimportant details, is very considerable (270 in the United States to date), and the reported experimental work, in measurement of power, efficiencies, and other essential engineering data, is large and increasing in volume. There is already quite enough to supply the needed material for our present discussion of the importance of superheating in promotion of efficiency and in its reduction of friction. In all, also, the process is the same: the conversion of the energy of heat, stored in the steam, into the kinetic energy of a jet; from which jet this energy is absorbed by intercepting it at the turbine vane and gradually transforming its *vis viva* into work while changing its path until, with complete reversal of direction and with velocity nearly destroyed with respect to the earth, the fluid issues at minimum velocity and with minimum unutilized, available, thermal or dynamic energy.

Parsons's Compound Steam Turbine dates from 1884.‡ It is

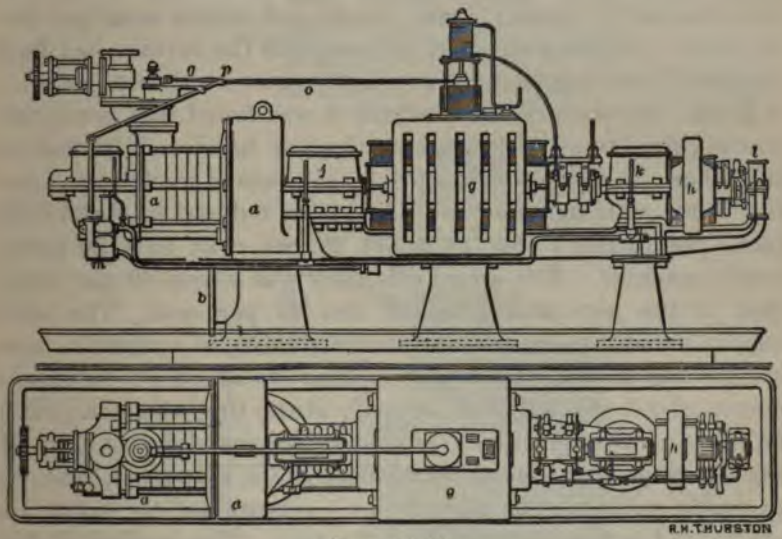
* Hero's "Pneumatica" (B.C. 120), Woodcroft's translation, 1851. "Le Machine deverse del S. Giovanni Branca," Rome, MDCXXIX. Stuart's "History of the Steam Engine," London, 1824. Thurston's "History of the Growth of the Steam Engine," International Science Series, New York, London, Paris, and Leipzig, 1878.

† See Ludwig Klein in *Zeits. des Vereines Deutscher Ingenieure*, October, 1895; *Revue de Mécanique*, vol. vii., 1900.

‡ "Description of the Compound Steam Turbine and Turbo-Generator," by the Hon. Charles A. Parsons, *Proc. Brit. Inst. Mechanical Engineers*, August, 1888, p. 480.

now the most extensively employed of the motors of this class, and has been constructed on so large a scale and of such high powers as to afford a very satisfactory set of data by which to judge of the promise of the type.

The first example of the machine ran, for some years, at a speed of 18,000 revolutions per minute; the second at about 10,000, driving a generator and providing current for the 60 lamps of the steamer "Earl Percy," on the Tyne. Mr. Parsons, in 1888, reported the efficiency of each element of his compound turbine as "theoretically" 89 per cent. and their combined effi-



FIGS. 62–63.

ciency as 87 per cent.; the passages in guides and turbines being properly proportioned to avoid the breaking up of the steady flow and continuous expansion of the steam. With careful lubrication, no wear was perceptible after several years of continuous working and no cutting action by the steam upon the parts of the machine was detected. The friction of bearings was found to be, at speed, over one-third of a horse-power each, cold, *but less than one-fifteenth when hot.* The normal output of the electric generator was 400 amperes at 80 volts, with a resistance of but 0.0025 ohm, in the armature, from brush to brush. The resistance of the field magnets was 23 ohms; electric efficiency 98 per cent., with 32,000 watts delivered, the engine

working non-condensing; the steam consumption was 42 pounds per electrical horse-power per hour, with 61 pounds steam pressure at the inlet, and as 35 pounds at 92 pounds pressure; the latter figure being practically equivalent to about 25 pounds per indicated horse-power per hour for a reciprocating engine. Since the date of that introductory report the figure has been much reduced, as shown elsewhere in this paper. At such speeds, as was to have been anticipated, the light and current were absolutely steady; there was no equivalent of the numerous minor forms of breakdown and accident only too familiar to us in the use of the reciprocating engine; costs were small, both of construction and of operation, and weight and volume small per unit of power. In four years after its inception the turbine had been supplied in an aggregate of over 2,000 electrical horse-power.

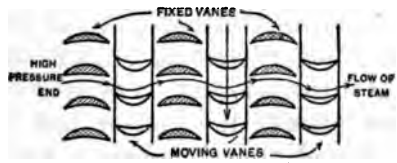
In the operation of the machine it was found that much care was required to avoid leakage on the one hand and friction on the other. Leakage was the principal cause of waste in the earlier forms, although clearances had been reduced to about 0.015 inch, permitting a loss of about 20 per cent. in a 50 horse-power machine. The actual efficiency was about 60 per cent.; that of the generator attached was 95 per cent. The ideal engine should, under similar circumstances of operation, non-condensing, give the horse-power hour on about 18 pounds of steam, about one-half that actually at the time attained (1888). In these pioneer machines, ground spindles and journals, yielding bearings and forced lubrication were employed, and the probable value of the machine as a compressed-air motor was recognized in the discussions of the time. The method of flow of steam, from vane to vane, is shown in the next sketch.

The design of the Parsons' turbine illustrates that scientific method which distinguished the work of James Watt and of others among our most famous and successful inventors of recent times. As stated by Mr. Parsons, the need was at the time recognized for a fast-running engine of fair economy in electrical work, and "the advantages of a steady running engine having no reciprocating parts, of small size and of extreme lightness were sufficiently obvious; provided that fairly economical results as to steam consumption could be realized."

The efficiency of the hydraulic turbine, which involves the same mechanical principles, gave promise of at least fair mechanical efficiency in the steam turbine, and the apparently

thermodynamic equivalence of the turbine and the piston engine, and the fact that the former is entirely free from the most serious of the extra-thermodynamic wastes of the latter, gave assurance of good economy in heat-conversion if the turbine could be practically operated in accordance with known principles of maximum efficiency. To keep down the speed of rotation, the turbine was compounded and a series of turbines was set on a common shaft, through which the steam passed suc-

FIG. 64.



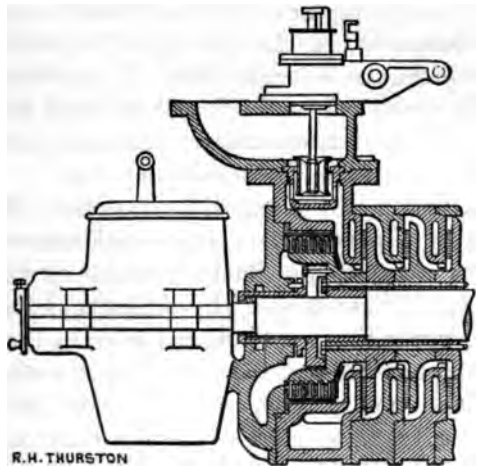


FIG. 65.

cessively, producing in each a thermodynamic effect proportional to the magnitude of that portion of the head availed of at each step, until the final element of the series rejected the steam into the air or into the condenser. The rotative speed was thus reduced in proportion to the number of turbines in series and the total thermodynamic efficiency was that due the total effective head and the net efficiency that due the thermodynamic operation, less friction and leakage wastes and the slight waste by conduction and radiation of heat.

The Parsons turbine was so far perfected in 1892 as to exhibit,

in a trial reported upon by Professor Ewing, an economy measured by 27.6 pounds steam per electrical horse-power per hour, at 95 pounds pressure. Later, the same authority reported upon a similar turbine, in fact, the same with alterations to adapt it to the higher pressure employed 115 pounds, and with superheated steam, 60 degrees Fahr. above the temperature of saturation. This test gave a steam consumption of about 20 pounds per electrical horse-power—a rise of 3 per cent. in heat-storage per unit weight of steam, and of 10 pounds in steam-pressure, giving a profit, in steam consumption, of about one-third, and in British thermal units, of about one-fourth; the principal gain being, presumably, due to the use of superheated steam, but not through reduction of heat-wastes.

In 1894, the work of the turbine had been so well and so satisfactorily tested, and the outcome had given such practical experience in designing, in construction and in operation, as to justify those interested in the new motor in seeking its experimental development on a larger scale. A syndicate was formed to test it in marine work, and a boat was built to develop high speed and to secure determinative measures of the value of steam turbines in driving the screw-propeller.

The first outcome of the experiment on the "Turbinia" was the discovery of a previously unsuspected cause of inefficiency at high speeds of rotation of the screw such as were adopted in this construction—"cavitation" by centrifugal action about the screw, which worked in a self-created cave in the midst of the water, throwing out the water faster than it could flow into the space by the action of gravity, even reinforced by the often still more active tendency to fill the vacuum thus caused. It was only when the speed of rotation of the screws had been reduced to 2,000 revolutions per minute, and after they were set in series of 3 on the same shaft, that the little boat made her famous run and attained a speed of 32¾ knots an hour, and later of 34½.

Trials of the "Turbinia" were reported on by Professor Ewing, thus:

"The mechanical friction of the turbines is particularly small, and the work spent on friction is not materially increased by increasing the range of expansion. This allows the steam to be profitably expanded much farther than would be useful or even practical in an engine of an ordinary kind. Apart from ques-

tions of friction, the addition of weight and bulk to allow for this extended expansion would be enormous in the ordinary engine; in the turbine it is very moderate. Steam is expanded nearly two hundredfold in the 'Turbinia,' and this is accomplished with engines which are much lighter than reciprocating engines of the same power, although in these the expansion would be much less complete. Rough weather was met with in some of the trials, and I had the opportunity of seeing that the 'Turbinia' is for her size a good sea-boat. The machinery worked with perfect smoothness; the screws did not race, and the bearings remained perfectly cool throughout. From first to last, during the whole of the trials, there was no hitch whatever or difficulty of any kind in the action of the turbines. Some twenty trial-runs in all were made under various conditions as to speed; the range of speeds tested extending from $6\frac{3}{4}$ knots to $32\frac{3}{4}$ knots. Full-speed trials were made on April 10th; the boat having then been in the water for fully a fortnight. Two successive runs on the measured mile, in opposite directions, in smooth water and at the slack of the tide, gave the following data:

TRIAL OF "TURBINIA."

Time on the mile	109.$\frac{1}{2}$ secs.	110 secs.
Corresponding speed in knots	32.79	32.73
Mean speed in knots	32.76	
Revolutions per minute of high-pressure and intermediate shafts	2,230	
Revolutions per minute of low-pressure shaft	2,000	
Steam-pressure in boiler by gauge	210 lb. per sq. in.	
Steam-pressure on admission to high-pressure turbine	157 lb. per sq. in.	
Greatest pressure in stokehold by water-gauge	$7\frac{1}{4}$ in.	

"The speed reached during this trial, 32.76 knots in the mean, is, I believe, the highest yet recorded for any vessel. It is greatly in excess of the speed hitherto reached in boats so small as the 'Turbinia.' It is clear, then, that the exceptional speed developed in the 'Turbinia' has been achieved without sacrifice of economy, and that the substitution of turbines driving high-speed screws, in place of reciprocating engines driving screws of much more moderate speed, is not attended with increased consumption of steam, so far as fast running is concerned."

The success of the "Turbinia" led to the construction, in 1899, of a naval "torpedo-boat destroyer," "Viper," and this

craft, only 210 feet in length, of 375 tons displacement, developing 11,000 horse-power on 15,000 square feet of heating and 376 feet of grate surface, in water-tube boilers, with steam at 175 pounds by gauge, at 1,050 revolutions of the turbines, made over 37 knots, above 43 miles, an hour. The contract speed was 35 knots. The turbines were two high and two low pressure, each driving a separate shaft carrying two propellers. The turbines were 35 and 50 inches in diameter. No vibration was produced by the engines and the engine room was so quiet that it was hardly possible to realize the presence of engines developing over 10,000 horse-power. Here, as in all craft of the sort, the extraordinary performance in power production, once all is understood, is that of the boilers; that of a horse-power for each $1\frac{1}{2}$ square feet of heating surface, and from each square foot of grate about 30 *net* horse-power. This is probably the most extraordinary phenomenon in this or any other example of marine engineering.

Steam turbines of great size and power are likely soon to be produced for many purposes, now that their performance has been found so satisfactory, and especially for torpedo-boat work, and their construction on a large scale will enable the engineer promptly to settle many questions of interest which the earlier work on small machines could not fully solve. It would seem that, as with the gas engines, the larger the scale of operation, the simpler the problems of design and construction and the easier the approximation of the real to the ideal in perfecting the system of energy conversion. Large turbines are comparatively low in speed of revolution, and it is considered that it would be entirely practicable to build an ocean steamer of large size, driven by turbines of 30,000 or 40,000 horse-power, or more if needed, at speeds of revolution as low as 400 per minute or lower, employing four shafts and eight screws, requiring minimum steam and fuel for their work, while economizing enormously in space and weight. There would be no vibration or noise annoying to passengers, and their simplicity of construction and freedom from the multitudinous bearings of the now usual construction of engine would give insurance against either breakdown or minor troubles and delays from heated journals, leakages about the engine, or other annoyances and expenses inseparable from the reciprocating machine. Steam pressures can be adopted at the maximum practicable with the steam

boilers of contemporary practice, whatever the limit may be. That limit will thenceforward always be found at the boiler.

The General Theory of the Steam Turbine is simple and is precisely that of the piston engine, so far as its thermodynamics are concerned. In both engines the heat stored in the fuel is transferred to a liquid which it converts into vapor, the heat itself being transformed into the latent heat of internal and of external work, in large part, and in lesser part transferred without transformation as the added sensible heat of the forming steam. The work of the period of vaporization consists of that of separation of the molecules of the liquid, the internal work, and of the expansion of the fluid, from the specific volume of the liquid to that of the steam, against the superincumbent steam pressure with displacement of a corresponding volume of steam from the boiler through the turbine. This change is succeeded by expansion from maximum to minimum pressure, practically adiabatically; for the temperature of every element of the enclosing metal is constant, and equal to that of the steam in contact with it, throughout the whole period of steady operation, and all the work of adiabatic expansion takes effect in the acceleration of the steam in the jet. The pressures and volumes have the same relation throughout this period of acceleration in the nozzle as behind the piston of a reciprocating engine; the law of Newton, "action and reaction are equal and opposite," automatically adjusting the resistance of acceleration to the instantaneous value of the steam pressure at every point in the path of the jet through the nozzle. The cycle-diagram of the turbine with complete expansion, whether simple or compound, is thus precisely the same as that of the ordinary engine of similar initial and back pressures and of equal ratio of adiabatic expansion; the latter being assumed possible, for the ideal case at least.

The reaction turbine and the impact turbine have this in common: that both convert heat-energy into work by the same thermodynamic process and both exhibit the same phenomena of steam production and utilization, thermodynamically. They have this difference: that the former accelerates the jet of steam actuating it, by its own rotation, and by the action of centrifugal force, and in such manner as to compel a higher resultant speed for a stated efficiency and such as to make the velocity of orifice, for unit efficiency, infinite; the velocity of the jet

relatively to the nozzle is also infinite while falling to absolute velocity zero; while the impact turbine receives the jet at the maximum velocity due the steam pressure behind it, simply, and steadily reduces that velocity to a minimum. The mathematical theory of both cases is perfectly well established and familiar, and need not be here recapitulated, so far as the non-thermodynamic mechanics of the problem are concerned.*

The impact turbine is that form in which the engineer finds most promise, and its study is worthy of some attention. Its ideal thermodynamic cycle, as already seen, is that of the piston steam engine, and modifications in practice are or may be the same, with the very important exception that the expansion line of the diagram may be always taken as adiabatic, the ideal being here attained—an impossibility with any other known form of steam engine or heat motor. The terminal and back-pressures may correspond to those of either the condensing or the non-condensing engine and the perfection of the diagram and of the cycle which it illustrates involves, as with the ordinary form of engine, the adoption of compression to an amount, in the case of incomplete expansion, proportional to the expansion, making the two ratios of expansion and compression equal, and, in the case of complete expansion, restoring the fluid by complete compression to maximum temperature and pressure in the liquid state by mechanical means solely; thus, in fact, producing the Carnot cycle.

The first discussion of the steam turbine, from the point of view of applied mechanics known to the writer, is that of M. Tournaire, who, in 1853, stated the problem and the conditions leading to its satisfactory solution in a very clear and comprehensive manner.† He says:

"The elastic fluids acquire enormous velocities under the action of very feeble pressures. To utilize these velocities conveniently, with simple wheels like the hydraulic turbines, it is necessary to adopt an extraordinarily rapid rotation, and to make the total section of the orifices very small, even for large deliveries of fluid. These difficulties may be evaded by causing the vapor '*or the gas*' (the italics are inserted by the translator)

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* See "Thermodynamics of Heat-Motors and Refrigerating Machines," by De Volson Wood; §§ 157, 158; pp. 309–317, for discussion of the turbine.

† "Comptes rendus de l'Académie des Sciences," March 28, 1853.

to lose its tension in a continuous and gradual manner, or by successive fractions, and making it react several times on the vanes of turbines properly arranged."

He then proceeds to illustrate by describing a series turbine, of the axial type, passing the steam through a succession of guide curves and turbine disks, alternately from the high to the low pressure side, substantially as practised by Parsons a generation later when "reducing the invention to practice," as Tournaire seems never to have done. This pioneer of 1853 proposes not only a series turbine, but a series of these machines, where the range of pressure may justify such complication, each multiple turbine discharging its steam at the limit of its expansion into the next turbine of a similar construction, but in structure entirely independent, and so on to the atmosphere or the condenser, precisely as the multiple cylinder or series steam engine may be made of a series of independent engines arranged to pass the steam from the boiler through one after the other, from smallest to largest between boiler and condenser. He further describes very clearly the sources of losses "tending to diminish the useful effect, as leakage, irregular flow, shocks, *tourbillonnements*, at entrance of the fluid into the guides and vanes, fluid friction in the channels, which may absorb a very notable part of the theoretic work." "Great care and precision" must be observed in the construction of a turbine to be actuated by a fluid of high tension and small density, and the lines of flow must be thoughtfully considered. The teeth of gearing employed at these immense velocities of rotation should be skilfully made, and it is probable, as he states, "that the helicoidal gearing of White may prove best," a form actually utilized by Dow many years later, and by Laval still later.

A successful steam turbine involves the determination of the precise forms and proportions of the jets supplying steam to the machine; their proper length and sweep; the similar problem of the vanes and channels in the wheel; the best speed of rotation and size of disk for the stated conditions; the safe construction of the revolving disks; the choice of a metal for these disks capable of safely sustaining the enormous stresses of centrifugal forces, and of carrying with safety, *and without distortion*, the buckets set on its periphery where not solid with the wheel; the provision of perfect static and running balance and equilibrium; the reduction of friction of disks spinning 25,000 revolutions a

minute, in some cases even more, in contact with high-pressure steam on the one hand and the vapor of the condenser or the air on the other, and the free and certain and economical lubrication of rubbing surfaces of metal in journals and bearings.

The principles involved in these several problems of detail are usually very simple, and are well understood by every well-informed engineer. The steam pressure must be as high as practicable; the fluid must develop fully its energy of flow from the latent energies of the steam stored at the boiler; these energies must be as gradually and steadily developed in useful form as possible, in guide channels formed so as to produce maximum velocity of delivery without loss by eddies or friction or leak. The steam should be delivered upon the wheel and entered into its channels without shock or leak or irregularity of flow, and must leave them with minimum mechanical energy, just flowing out of the way of the succeeding particles. Speeds of rotation must be precisely those exacted by the pressures adopted; proportions of receiving and delivering sides must be similarly adapted to the work; materials must be not only strong but tough; fits must be accurate, without permitting contact of parts having rapid relative movement; lubrication should be effected with a suitable unguent flooding the parts; steam should be superheated, and the vacuum as perfect as possible.

In all forms the obstacles to be overcome by the engineer are the same and, as a rule, similar expedients are adopted by all for the purpose. In all, the speed of linear travel of the turbine vane must be enormously great, too great, by far, for satisfactory attainment, or for convenient utilization in connection with other mechanisms, and in all the ultimate velocity of exit from under pressure cannot be made, after a moderate pressure is attained, to increase with rising boiler pressures, if issuing from plain orifices; and in all it is a problem of importance to secure the issue of the steam in a compact and well-defined jet, capable of being directed with precision into the receiving buckets of the wheel. To secure this compact jet and to turn it, at its enormous velocity of issue, into buckets flying at not less than one-half this velocity, and in them to so manipulate the kinetic energy of the fluid as to absorb without waste any large proportion of its total, constitutes the problem for all—a very simple but a somewhat difficult one, and one which

does not permit departure from very simple and inflexible principles and processes.

The principles are precisely those of hydraulic-turbine construction and operation:

1. The full energy of the available head should be developed. This may, as in the water-wheel, be either developed by immediate and complete conversion into the kinetic energy of a freely-moving jet, before any portion is transformed into useful work, or it may be partly developed as purely kinetic energy and partly as the energy of pressure overcoming the resistance of the load directly, as illustrated in the case of the hydraulic motor, by the impact and the pressure turbines. Ordinarily, however, the steam turbine, even more than the water-wheel, is best operated on the first system, as it is less liable to leakage or waste.

2. All sources of waste, during the process of production of utilizable kinetic energy, as through friction, leakage or irregularity of flow, or in the form of a jet, should be anticipated and provided against effectively in such manner that the full amount of available primary energy may be developed.

3. The transfer of the energy of the jet to the turbine should be completely effected. The jet should be directed, precisely, into the buckets; it should be taken into the passages of the wheel without disturbance of its flow; should be guided steadily and smoothly into a reversed path; should be brought to a relative velocity on the vane nearly equal to the velocity of the latter with respect to the earth, and should be then allowed to issue with minimum final velocity and store of kinetic energy, and with expansion as complete as practicable, into the atmosphere or the condenser. Meantime, the passages should be smoothly graded in cross-section from the point of reception of the jet to the point of discharge, in such manner that the law of flow just enunciated should be maintained and the proper relation of increasing volumes and decreasing pressures preserved, without sudden variations of rate of flow.

These principles being observed, the form of the apparatus or the type of the machine may have no influence upon the efficiency attainable; but the compliance with these conditions of maximum effect, while seeking low speed of rotation and the satisfaction of the demands of practical construction and application to specified purposes, may involve, as elsewhere seen,

the exercise of much ingenuity and great constructive skill, and may give rise to a variety of forms of detail. The essential requirement at the point of delivery of the current upon the turbine is attained by careful shaping and proportioning of the nozzle with a view to insuring steady volumetric change and steady flow, from the interior of the boiler to the orifice, from which a compact and straight-lined jet is to issue. The essential requirements in receiving the jet upon the wheel and in converting its kinetic energy into useful work, are the smooth and gradual change of section of the wheel passages from point of reception to point of final delivery of the fluid from the turbine, while providing for equally smooth and steady change of direction of flow, relatively to the wheel and to the earth, in such manner that the flow will be ultimately completely reversed on the wheel and reduced to as nearly zero as may be found practicable with respect to the earth; and while securing freedom from wastes by leakage, by friction or by non-adaptation of the speed of rotation of the wheel to both the speed of the jet and the velocity of rotation of the driven mechanism. Meantime, the reduction of fuel and steam consumption to a minimum thus assured should be accompanied by a reduction to a safe minimum limit of the weight, volume and rotative velocity of the turbine. The delivery velocity of the jet is usually, in the Laval practice, at least, about 3,000 feet per second; that of the receiving edge of the wheel should be about one-half this speed, or respectively 35 and 17½ miles per minute (2,100 and 1,050 miles per hour). The velocities are actually usually about 1,200 feet per second, nearly 15 miles per minute and 840 per hour, figures which obviously involve enormous centrifugal forces and as extraordinary strength in the materials of which the turbine disk must be composed.

The stored energy of the jet, per unit of weight, is

$$E = \frac{Wv^2}{2g};$$

which, for the above velocities per second of the effluent steam, becomes

$$E = 3{,}000^2/64.4 = 140{,}000 \text{ foot-pounds, nearly,}$$

for each pound weight of steam supplied. This energy is so great and the inertia of the mass so effective, that it is found

by direct experiment that there is very little tendency for the jet to expand laterally, where permitted opportunity to move forward, as when entered into the wheel-passages immediately on issuing from the jet-nozzle. It is also evident that the design of the turbine is, apart from properly proportioning the passages, mainly a problem in meeting the inertia or centrifugal stresses, and that the steam pressures dealt with are comparatively unimportant. It is for this reason that, in small turbines, the passages are milled out of solid steel disks and that, in all cases, metals of high tenacity are selected for their construction.

Where the compound-turbine is adopted, and the velocity of rotation is reduced to a fraction of that exacted in the simple turbine of high efficiency, strength of material is less a problem; but, even with the lowest speeds as yet secured, these forces are not to be ignored. With the compound-turbine, the same proportions of successive sections of wheel and guide passages are to be provided; but they are distributed over a path which wanders from jet to wheel, to guide, to wheel again —from the one to the other alternately—sometimes, as in some of the Parsons turbines, through the passages of 30 or even 40 disks and their accessory guides. The proportions are easily determined by laying down the adiabatic curve for the case assumed and making the passages follow in their relative sections the order, relatively to pressures, thus found. For velocities, the formula of Zeuner may probably be accepted as substantially correct. This gives, for expansion from 6 atmospheres to 1, a velocity of outflow of jet of 2,600 feet per second and the velocity into a vacuum, giving 0.1 atmosphere back-pressure, from the same initial pressure, 4,600 feet.

The discharge may be computed by Napier's formula,

$$W = \frac{pa}{70};$$

where W is the weight discharged per second; p is the absolute steam pressure in pounds per square inch; a is the area of the orifice in square inches; and 70 is the constant determined by Napier's original experiments. This formula was checked by a series of experiments in the Sibley College laboratories, in 1897–8, using a nozzle of the type employed in the steam turbine, but only $\frac{3}{8}$ inch in length and with carefully

rounded entrance, and while shapes and proportions of nozzles and method of dealing with the outflowing steam in measuring it were found to affect the results, it was concluded that the formula was substantially correct for the case in hand.

The wastes of energy in the steam turbine differ, in some respects, as to character from those of the common type of engine, and consist of losses by conduction and radiation, in small proportion from the exterior of the system, as in the ordinary machine, of friction wastes of small amount in the turbine, so far as produced by rubbing of parts in contact, as contrasted with comparatively large amounts in the reciprocating engine, and of often large amounts of fluid friction in the turbine within the working apparatus as compared with very small quantities within the steam cylinder of the piston machine; while the latter is subject to large losses through "cylinder condensation" for which no equivalent appears in the turbine. Leakage probably is the cause of much larger wastes in the turbine, proportionally, than in the standard engine. Vibration and jar occur, in serious degree, at times, with the reciprocating engine and are absent from the properly built turbine.

Of these losses, the external wastes by radiation and conduction can be, in either engine, made unimportant by careful protection by non-conducting coverings; leakage requires more perfect construction in the turbine for its extinction than in the ordinary motor; friction in the former is so largely internal, and especially is in such proportion fluid friction, that it is in less degree subject to absolute waste as energy; since it is productive of heat in full proportion and this heat assists in maintaining the steam dry during the period of expansion and promotes adiabatic expansion by compensating the losses of heat externally. By extending the period of expansion also, until an equivalent amount of energy is developed, before rejection from the turbine disk, this equivalent heat and work can be regained in cases in which the expansion is not originally complete, always provided, of course, that the added work of expansion does not exceed, in total cost, the value of the recovered energy. The comparatively large internal friction thus affords opportunity for recovery in the turbine in larger proportion than in the ordinary machine.

We have found reason to believe that the friction of fluids in contact with the spinning disk of the turbine or in the eddying

stream of fluid may have an important influence upon the efficiency of the turbine at such enormous speeds of relative motion as we find in this apparatus. The total friction of the 10 horse-power Laval turbine of Sibley College is 2.4 horse-power, nearly $\frac{1}{4}$ its ratio delivery, and practically constant, of course, at all loads. The rate of absorption of energy of a turbine disk spinning, initially, 15,000 revolutions per minute, in steam at atmospheric pressure, was found by Wissler, at Sautter-Harle, to be, as a mean, 3,000 revolutions per minute, and the whole energy of the disk considered as flywheel was lost in 5 minutes, converted into the work of friction of disk and bearings, apparently in nearly equal parts, and reconverted into wasted heat.

A weight of 10 pounds, spinning with a mean velocity of only 100 feet per second, would store energy amounting to

$$10 \times 10{,}000/64.4 = 1{,}553 \text{ foot-pounds.}$$

At the more common mean velocity of high-speed turbines, it would store

$$10 \times 90{,}000/64.4 = 13{,}977 \text{ foot-pounds.}$$

If this were lost in five minutes, the deduction follows that about 2,800 foot-pounds may thus be transformed into friction per minute and within an atmosphere of dry steam issuing from a non-condensing turbine, or if the turbine be rated at 10 horse-power, a mean of about 1 per cent. of its nominal power, a loss increasing with the proportion of moisture present; while at the maximum the loss would, at uniform full speed, be several times that figure.

Leakage is obviously a serious matter with these motors, and the closest of fits and finest of workmanship are needed to insure against a large loss of efficiency through this action. When it is realized that a nozzle of a square-inch section may supply steam for 300 to 500 horse-power in steam motors, and that a clearance of but one one-hundredth of an inch around the circumference of the turbine-disk will permit some such waste, it is easily seen that here may often be a reason for the falling off of the output and the economy of the machine 50 per cent. or more. The desideratum at this point is absolute tightness of fit with no liability to rubbing friction and variation of fit with pressure or temperature. It should be possible to secure an efficiency with the steam turbine, practically equal to that of

the best hydraulic turbine, approximating 80 per cent., but not until fluid friction and leakage can be substantially suppressed.

The Rankine cycle being taken as representative of the ideal case of the turbine as now constructed, we find that the measure of the utmost effective work of the machine operating between p_1 and p_2, T_1 and T_2, as deduced by both Rankine and Clausius, is

$$U = J \left(\int_{T_2}^{T_1} C \frac{T_1 - T_2}{T_1} .dT + \frac{T - T}{T_1} .r \right);$$

where measured in dynamic units and when U is in foot pounds J is 778; C is the specific heat of the liquid at absolute temperature T_1; and r is the latent heat of vaporization at the same temperature in thermal units. All the constants are well-known and very accurately determined by Regnault and his successors. The quotient of this quantity, in any given case, by the mechanical equivalent of the heat supplied in production of the steam yielding this work, measures the efficiency of the operation; which rarely equals one-fourth in the very best of existing actual heat-motors and which is now usually about 20 per cent. in the best classes of steam engines operating with dry steam of high tension and with large expansion.

Approximate expressions of convenient form and sufficiently accurate for general use by engineers have been proposed by various authorities, among whom Rankine was one of the most successful; as, for example, where he finds, for the case of the non-conducting cylinder, the equivalent of the case in hand:

Energy per cubic foot of steam admitted,

$$E_v = r\, p_e = r\, (p_m - p_2) = p_1\, (10 - 9r^{-\frac{1}{2}}) - rp_2;$$

where r is the true ratio of expansion; p is the mean effective pressure; p_m is the mean total pressure; p_2 is the back pressure; all in British units, pounds, feet, and foot-pounds.

The heat expended is similarly found to be, approximately, in foot-pounds per cubic foot:

$$HD/r + (13\tfrac{1}{3} p_1 \times 4{,}000) \div r;$$

where H is the heat per pound and D the weight per cubic foot of the fluid; p_1 is the pressure per square foot, as above, at the boiler.

STEAM-TURBINE CYCLES.*

Rankine-Clausius Cycle: No Compression.

Ideal case; $p_2 = p_3 = 2$; condensing; $T_3 = 587°$.

p_1	150	200	250	300	350	400	450	500
T_1	819.22	842.63	861.88	878.369	892.96	905.9	917.62	927.2
r	14.87	19.34	25.	27.4	31.4	35.4	39.17	43.02
V_3	44.04	43.25	42.6	42.06	41.55	41.25	40.82	40.5
H_1	858,289	863,813	868,411	872,323	875,827	878,890	881,707	885,000
U	197,624	212,305	223,805	233,120	232,231	242,042	256,526	262,050
E	23.	24.5	25.87	26.7	26.5	27.5	29.09	29.6
M.E.P.'	4,521	4,908	5,188.7	5,260	5,583	5.875	6,170	6,375
M.E.P."	31.16	34.2	35.5	36.6	38.77	40.75	42.64	45.5
A	11,065	10,386	9,910	9,875	9,603	9,254	8,748	8,600
B	2.3	2.29	2.28	2.27	2.26	2.25	2.25	2.24
C	10.	9.35	8.88	8.52	8.54	8.36	7.7	7.57
W	11.4	10.7	10.3	10.2	9.9	9.3	9.0	8.9
F	1.107	1.03	.991	.987	.96	.925	.875	.843
D	440.4	397.	387.1	376.2	355.	328.	316.	306.3
D'	7.3	6.7	6.4	6.2	5.9	5.6	5.3	5.1

Carnot Cycle: Full Compression.

Ideal case; $p_2 = p_3 = 2$; corresponding to $T_2 = 587°$.

p_1	150	200	250	300	350	400	450	500
T_1	819.2	841.6	861.9	878.36	892.9	905.92	917.6	928.4
r	44.8	57.8	70.4	82.63	94.6	106.5	118	129.6
V_3	133	130.4	128.4	126.83	125.4	124.2	123.3	122
H_1	671,000	656,000	646,097	636,604	628,219	620,797	613,000	607,618
U	190,000	198,500	205,000	210,079	218,900	218,500	221,000	222,000
E	28.3	30.3	31.9	33.1	34.2	35.1	36.	36.7
M.E.P.'	1,427	1,522	1,604.9	1,695	1,712.1	1,758.2	1,800	1,820
M.E.P."	10.01	10.56	11.13	11.55	11.85	12.2	12.5	12.7
A	9,000	8,430	7,986	7,730	7,450	7,236	7,050	6,934
B	2.95	3.02	3.08	3.11	3.15	3.19	3.23	3.26
C	10.45	9.98	9.69	9.4	9.2	9.0	8.94	8.89
W	9.32	8.73	8.27	7.93	7.73	7.49	7.32	7.19
F	.90	.832	.799	.773	.745	.724	.705	.698
D	1,390	1,300	1,236	1,190	1,157	1,115	1,100	1,090
D'	22.8	21.7	20 6	19.9	19.28	18 58	18.3	18.1

The Ideal Rankine Non-conducting Engine, with 2 pounds back pressure, and a terminal pressure on the expansion line of 7 pounds per square inch, should have an efficiency measured by a consumption of heat in British thermal units per horse-power per hour of about

$$H = 20{,}000/log.\ p_1 \text{ (ideal)}.$$

* "Standard of Efficiency for Heat Engines," *Journal Franklin Institute*, December, 1896, January, 1897, R. H. Thurston; also "Manual of the Steam Engine," fourth edition, p. 1002. *Trans. A. S. M. E.*, 1891.

A criterion by which such an engine may perhaps be best judged and compared with other steam engines of varying conditions, especially steam pressure, is the magnitude of the value of the constant a in the expression for quantity of heat consumed, per horse-power per minute or per hour, already given,

$$H = \frac{a}{\log p_1}.*$$

The values of the constant a have been found to be, for the ideal case of Carnot, about 18,000 British thermal units per *hour*, and to range upward to 36,000 for the best classes of simple engines; while the best examples of triple and quadruple expansion machines give, respectively, about 27,000 and 26,000 where p_1 is the steam pressure in pounds on the square inch.

The best records for the simple engine with dry and saturated steam, to date, appear to approximate

$$H = 36{,}000/\log.\ p_1 \text{ (simple)};$$

those for the best compound engines similarly approach

$$H = 32{,}000/\log.\ p \text{ (compound)};$$

those for the best class of triple-expansion engines give

$$H = 27{,}000/\log.\ p_1 \text{ (triple)},$$

and those for the best class of quadruple-expansion engines attain approximately

$$H = 26{,}000/\log.\ p_1.$$

For dry, saturated steam, such as is probably fairly to be assumed to be secured with moderate superheating in the steam turbine and where only adiabatic condensation takes place, Rankine obtains approximations, thus:

Energy exerted on the engine by one pound of steam—

$$U = v_2 \left\{ p_1 (17\, r^1 - 16\, r^{1\frac{7}{16}}) - p_3 \right\};$$

where v is the volume at the end of expansion; p_1 and p_3 are the initial and back pressures; r the total ratio of expansion as before.

* See "Manual Steam Engine," vol. i., chap. viii.; *Trans. A. S. M. E.*, 1899.

Heat expended per pound of steam:

$$H = 15\tfrac{1}{2}\, p_1 v_1 = 15\tfrac{1}{2}\, p_1 v_2 / r^*.$$

MM. Rateau and Rey have found approximate expressions for metric measures of the consumption of steam for the ideal case, the quantity of work per unit weight being the maximum, as above, and give

$$K = 0.85 + (6.95 - 0.92\ log\ p_1)/(log\ p_1 - log\ p_2);$$

where p_1 and p_2 are the initial and final pressures.†

Pressures are in kilograms per square centimeter; K in kilograms per metric horse-power hour. The formula is stated to be correct to within 0.002, for values less than 15 kilograms per horse-power hour. M. Rateau calls attention to the fact that the formula exhibits clearly the advisability of insuring a low back-pressure and, with condensation, a very perfect vacuum.‡

Professor Mollier, in 1898, proposed the following:

$$K = (6.85 - 0.9\ log\ p_1)\ /\ (log\ p_1 - log\ p_2),$$

which is a trifle less accurate, but simpler.§

The proportion of steam condensed in adiabatic expansion is known to be accurately:

$$m_e = 1 - T_2/H_2 \cdot (J\ log_e \frac{T_1}{T_2} + \frac{H_1}{T_1});$$

where T_1 and T_2 are absolute temperatures, initial and final, and H_1 and H are corresponding latent heats of vaporization. The values of m_e range, from insignificant amounts, in the older forms and proportions of engines employing low steam pressures, to about $1\frac{1}{2}$ per cent. per unit ratio of expansion, as operating in modern engines at high pressures and as observable in the steam turbine.‖ For example: it amounts to 15 per cent. in expanding, as in the triple-expansion engine, from 140 pounds

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* Rankine's "Prime Movers," part iii., chap. iii., sec. v., p. 375. Thurston's "Manual of the Steam Engine," vol. i., chap. v., p. 421.

† "Annales des Mines," Fevrier, 1897.

‡ "Rapport sur les Turbines à Vapeur," *Congres International de Mécanique*, Paris. 1900.

§ *Zeitschrift des Vereines deutscher Ingenieure*, June, 1898.

‖ "Manual of the Steam Engine," vol. i, pp. 439–440.

to 7 and to 10 per cent. between 140 and 20 pounds, absolute, and is nearly in proportion to the ratio of expansion at low initial pressures and moderate cut-offs.

The Discharge from Steam Nozzles, and orifices in thin plates as well, differs very greatly from the discharges from similar conductors of liquids, since the elasticity of the fluid comes into play and the ratio of pressures, initial and final, in practice is very great in the steam motors. The weight flowing from the nozzle, per unit of time, is measured by

$$W = VDS;$$

where V is the velocity, D the density of the fluid at the point taken for measurement, and S is the section of the current at the same point. With the liquids, where density is constant, the section is thus proportional to the weight discharged; but the vapors and gases have a varying density during flow and, as the pressure falls and specific volume increases, the weight discharged, increasing at first, soon becomes a maximum and thenceforth decreases with falling tension. This point of maximum discharge is found at about $p_2/p_1 = \frac{1}{2}$ for the gases and about $p_2/p_1 = 0.6$ with vapors, at all initial pressures. For steam, the ratio is usually given as about 0.58. This action was detected by Napier in experimental work and explained by Rankine, then engaged in the study of the thermodynamics of the case.*

It follows from this that, to secure full delivery and continued acceleration of the jet, the nozzle should converge from the point of maximum pressure within to a minimum section where discharging the total flow at 0.6 initial pressure and should thence diverge as pressures continue to fall, and in proportion to such drop. The exit orifice should thus be given, finally, a section proportioned to that of minimum section, for $p_2 = 0.60\ p_1$, as the latter pressure is to p_3 at final discharge from the system.†

If the jet is not thus let down to the pressure of the atmos-

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* Rankine's "Prime Movers," p. 298. London *Engineer*, September, October, November, December, 1869. See also Rateau, "Rapport sur les Turbines," 1900.

† It has been found that the maximum velocity at the point of greatest contraction is very nearly if not quite that of sound in the fluid, at that point and in that state as to pressure and volume.

phere, the condenser or other receiving medium, it expands to that minimum immediately at exit and enlarges its section in similar proportion and is then ready to surrender its energy. The nozzle thus is to be given a converging or a diverging form, accordingly as the pressure at its exit is greater or less than the critical tension just indicated, and as illustrated by the long-current practice of the makers of Giffard's "injector" and perhaps of still earlier makers of apparatus in which such a jet is sought. The earliest turbines of Laval, and his predecessors even, illustrate the fact enunciated by the inventor, that diverging nozzles must be employed, if seeking to obtain the full advantage of the fall of pressure, from initial to terminal, outside the turbine wheel. The discharge of steam from the nozzle is thus independent of the final pressure when the latter is less than 0.6 the initial pressure, although a function of that tension at higher proportional tensions.

The computation of the velocity, V, of flow of jet is effected by expressions like, or equivalent to, that of Wantzel and Saint-Venant as early as 1839,* in a discussion of experiments on the flow of air.

This equation has the general form

$$V_2 = \int_{p_2}^{p_1} v \, dp;$$

which can be integrated when the relation of v to p can be established for the assumed conditions, as for isothermal or for adiabatic expansion, and when the values of constants in the familiar expression, pv^γ = constant, can thus be determined. In the present case, the expansion is, in steady working, adiabatic actually as well as ideally; $\gamma = 1.135$, and we have

$$V_2^2 / 2g = p_0^{\frac{1}{\gamma}} v_0 \frac{\gamma - 1}{\gamma} \left(p_1^{\frac{\gamma-1}{\gamma}} - p_2^{\frac{\gamma-1}{\gamma}} \right);$$

in which values may be inserted to correspond with the conditions assumed. Grashof has proposed the approximate and simple formula for the case in which the final pressure falls below the critical,

$$W = 15.26 \, p_1^{0.97},$$

* *Journal de l'École Polytechnique*, vol. xxvii.

and Rateau offers

$$W = 15.42\, p_1^{0.97};$$

where W is in grams per second and per square centimeter of orifice, and p_1 is in atmospheres.

Otherwise deduced, we may assume that the energy of the jet is that of the graphic representation of the cycle, either entropic or pressure-volume. Hence, if we divide the measure of the horse-power, 550 or 33,000, or 1,980,000, for the selected unit of time, by the work, U, of the ideal diagram, the quotient is the measure of the number of units of weight of fluid required per horse-power, $W_s = 33{,}000 / U$. Thus we have, also, the expression, on the assumption just made, for energy produced in kinetic form,

$$V_2^2 / 2g = 550 / W_s = U;\ V_2 = \sqrt{550 \times 2g / W_s}.$$

In metric measures,

$$V = 100\, \sqrt{530 / K};$$

where V is in meters per second and K is the steam consumption per horse-power in kilograms. Rateau gives also the approximate formula for V:

$$V_2 = 418\, m\, (1 + 0.065\, log\, p_1),$$

where m represents the meter, p_1 the initial pressure, the terminal being $0.6\, p_1$.

The Graphics of this Case may be illustrated either by tracing the "p-v history" of the unit-weight of steam throughout its cycle or by studying the "theta-phi diagram," the dynamic and the thermal graphical representations of the complete cycle of changes of pressure and volume, and of temperature and entropy which are synchronous with the kinematic cycle of the apparatus; passing through which cycle, each mass of fluid, and each unit of heat finds itself related precisely as at a point in time marking the similar point in the preceding engine-cycle. This cycle is easily followed in the case of the piston engine, as it corresponds precisely and necessarily with one revolution, or kinematic cycle, of the engine crank; but it is less readily defined in the case of the steam turbine.

What actually happens is either the following or an equivalent series of operations: Taking unit-weight of fluid employed as the working substance, we find in this case a pound of water, as

will be assumed, entering the boiler, is presently, under boiler-pressure, raised to the temperature of the steam, with slight increase of volume, then, with no further change of temperature, but with large accession of heat, it is expanded from the specific volume of water to that of the steam; meantime the fluid accepting heat of two nominal sorts: one quantity measured by the product of the range of temperature into the mean specific heat of the fluid, the other the "latent heat," which is transformed automatically into work and employed in overcoming molecular resistance to expansion and vaporization and in the external work of overcoming the resistance due the pressure of the atmosphere of vapor into which the steam is forced. The first, the actual energy, is stored as heat; the latter, the potential energy of the molecular system of the vaporized fluid, can only reappear on the condensation of the vapor into the liquid again. The changes of pressure and volume of the fluid, in these, as in all physical changes, are mutually related, and the laws and the magnitudes for the case are well-known. The next movement in the cycle is the transfer of the mass of steam to a point of exit where the fluid expands, adiabatically, through an ajutage, a nozzle, in which all the available thermal energy is, by thermodynamic transformation, converted into the kinetic energy of a jet of steam, issuing with a velocity determined by the magnitude of the store of energy thus utilized. In this process of transformation of stored and potential energy into *vis viva*, the inertia of the freely-moving particles automatically supplies the resistance exactly balancing the expansive effort, at each instant, of the expanding vapor, and the relation of pressures and volumes is precisely that observed where, as in the reciprocating engine, the steam expands behind a piston and the same quantity of heat is converted into work by the same series of variations of pressure and volume; the "p-v history," or the "theta-phi history," of the fluid, during the turbine cycle, and at every step in this progress, is precisely the same as with the corresponding engine-cycle so familiar to the engineer as his "ideal" indicator diagram.

The Ideal Cycle for the steam turbine corresponds more closely with that of the real engine than does the ideal of any other form of motor, in accord with its real and practical representative. In Fig. 66, herewith, are grouped the principal representative thermodynamic cycles of both the gas and vapor engines.

Among these will be found the ideal cycle for all familiar forms of vapor engine. It is No. XVIII., but properly including the triangular terminal area, *it* v'_2, of the vapor-cycle diagram, which marks the difference between the ordinary Clausius and the common Rankine ideal cycles; either of which, however, it may simulate. So far as the process of heat-conversion is concerned, that in which the stored heat-energy of the working fluid is transformed into work by expansion, the turbine cycle is ideally perfect; this expansion line being combined with complete adiabatic

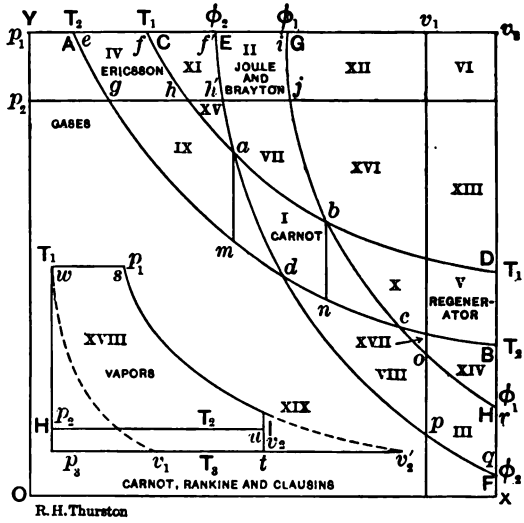

FIG. 66.

compression to produce a Carnot cycle and the perfect heat engine diagram.

This cycle is also capable of modification, as with the common engine cycle, restricting the volume of the fluid at the termination of the period of expansion within the machine, as is customary in the reciprocating engine, in compliance with the demands of financial and commercial economics. In fact, the steam turbine can be made to closely, if not accurately, reproduce the Rankine cycles, either with or without adiabatic compression, and, in actual operation, to approximate the ideal more closely than other engines, both in form of cycle on the pressure-volume chart and in actual utilization, by thermodynamic conversion, of the heat-energy supplied it.

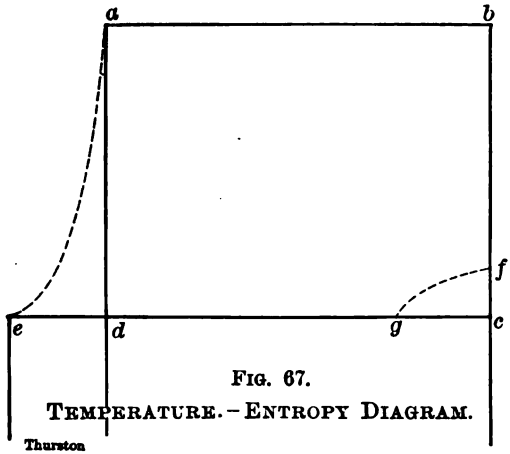

FIG. 67.

TEMPERATURE.–ENTROPY DIAGRAM.

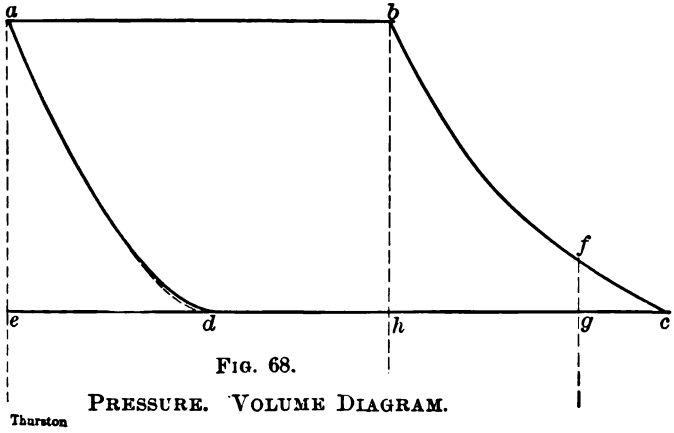

FIG. 68.

PRESSURE. VOLUME DIAGRAM.

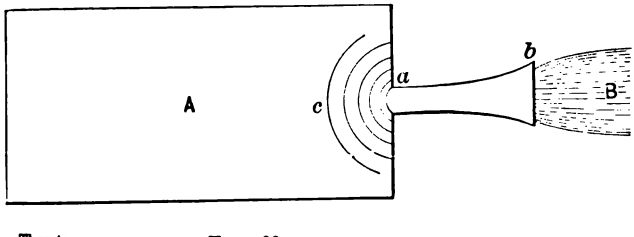

FIG. 69.

THE STEAM JET.

Studying the cycle in detail and as modified from that of the "perfect engine" by the omission of the compression line and by incompleteness of expansion, we may compare the two diagrams in which the co-ordinates are, in the one case, pressure and volume; in the other case, temperature and its complementary factor "entropy"; both diagrams representing the same quantity of energy—that which is derived, in such a cycle as is taken in illustration, by the employment of unit-weight of the fluid.

In the diagrams, Figs. 67 and 68, the perfect engine cycle is represented by *abcda*, the cycle of Rankine or of Clausius, with its complete expansion and without compression, by *abcdea*. In the former, both expansion and compression, *bc* and *da*, are complete and adiabatic and the efficiency of the cycle is necessarily, for the ideal case, for the turbine, as for the common form of engine, the maximum, Carnot, efficiency:

$$E = (T_1 - T_2)/T_1.$$

In the second form, in which there is no complete compression or other, but in which the restoration of the fluid from minimum to maximum temperature and pressure, and from minimum to maximum volume, is effected by expenditure of heat otherwise capable of thermodynamic utilization, the cycle is modified and the diagram becomes thus altered, at the left, by the transfer of its boundary from *da* to *ea* with a loss of efficiency measured by the defect shown by the loss of area exhibited by the conversion of the rectangular area into the triangular, as at *ead*, on the temperature-entropy diagram in Fig. 67, a modification of efficiency which does not appear so satisfactorily on the pressure-volume diagram. The magnitude of the utilized energy is easily shown to be in the second case:

$$U = J\left[T_1 - T_2\,(1 + \log_e T_1/T_2) + \frac{T_1 - T_2}{T_1} \cdot H_1\right] + (p_2 - p_3)\,v_2;$$

where T_1 and T_2 are the temperatures and p_1, and p_2 are the pressures at the beginning and at the end of expansion and p the back pressure, v_2 the final volume for the case of incomplete expansion.

The increased expenditure of heat, in the second case, that of the Rankine ideal cycle, is shown on the theta-phi diagram as *ead*

and the work gained is seen to be, on the *pv* diagram, *ead*; their ratio is obviously less than one half that of the work, *abcd*, to the heat expended, in the Carnot cycle.* The net result is thus a decided loss and its magnitude in any example may be computed by comparing heat supply and work performed in the two cases.†

It will be noted that, in the preceding algebraic expression for work performed, the last term within the brackets measures the work done and the efficiency of the Carnot cycle; the balance of the bracketed quantity must evidently measure the difference of work for the two cycles for equal differences of temperature and ratios of expansion, but the fact that the gain of work in the Rankine, or the common Corliss, engine cycle over that of Carnot involves a net loss of heat and efficiency, a loss of heat more than the equivalent of the gain in work, is not shown by the diagram and must be found by computation or by comparing the two diagrams drawn to a common scale of energy.

Fig. 69 shows the simplest case of development of energy in the jet, and its storage by conversion from heat energy, in a diagrammatic manner. From *a* to *b*, the work of expansion occurs adiabatically; the work of vaporization taking effect within the vessel *A* in which steam is made and producing that acceleration and kinetic energy which is observable at *c* and up to the point at the nozzle at which the adiabatic expansion commences. The work in *A* is shown on the pressure-volume diagram as *abhe*; that of adiabatic expansion is *bchb*. Passing out, along the path *B*, the fluid stores all the energy measured by the diagram, in the form of *vis viva*, which is to be presently absorbed by the impact turbine. As the store of steam and of energy in *A* is necessarily constant in steady working, it is obvious that all the energy of the vaporization period must enter the jet.

Formal Engine Trials to determine the efficiency in practical operation of the steam turbine are now available in considerable number and among them and in addition to the special investigations made in Sibley College, there are some which

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* "Manual of the Steam Engine;" vol. i., chap. i., p. 434.

† *Ibidem;* Chap. ix. and Appendix; tables and examples. Also *Trans. A. S. M. E.*, various papers on "Engine Efficiency," etc.

throw light upon the question of the extent and manner of gain in efficiency obtainable by the use of superheated steam. Among the earliest of these were those of Professor Ewing, in August 1892, in which the Parsons compound turbine was tested. The report upon his investigations includes the following as the main features in data and results of test:

The general behavior of the machine was similar, in respect to efficiency and its variations, to that of the ordinary piston engine. The so-called "law" of Willans was illustrated and the performance of the turbine was practically equivalent to that of a good compound engine of the ordinary type and under similar conditions of operation and of cycle. The consumption of steam was 27.6 pounds per electrical horse-power at 95 pounds steam pressure, and with moist steam, in the earlier tests of 1891. The later tests here quoted exhibit decided gain by superheating; the figure falling to about 20 pounds with a superheat of 60 degrees Fahr.

In this case, jet-condensers were employed, giving about 28 inches vacuum; the speed of turbine was 4,800 revolutions per minute; the attached generator delivered an alternating current at 2,000 volts and, at rated power, 60 amperes, with 80 alternations per second. Its electrical efficiency was 97½ per cent. The steam pressure at the boilers was 140 pounds by gauge.

The following are the tabulated data obtained during these trials:

TABLE I.

GENERAL RESULTS OF TEST.

	Pressure by gauge on boiler.	Temperature of Steam.	Load in K.W. per hour.	Feed water per hour, Pounds.		
	Lbs. per sq. in.	Deg. F.		Total.	Per K W.	Per E. H. P.
Continuous current moderate superheating.	96	335	0.1	480	.....	.....
	102	365	10.2	760	74.5	55.6
	100	356	27.0	1,110	41.1	30.7
	102	400	49.2	1,590	32.3	24.1
	100	390	74.5	2,170	29.1	21.7
	103	398	102.0	2,900	28.4	21.1
Continuous current, high superheating.	102	463	28.3	1,060	37.5	28.0
	102	468	49.5	1,480	29.9	22.3
	101	465	78.4	2,170	27.7	20.7
Alternating current, moderate superheating.	99	367	31.6	1,180	37.3	27.8
	97	394	49.9	1,550	31.1	23.2
	103	399	105.2	2,970	28.2	21.0

TABLE II.

CONSUMPTION OF FEED WATER AT VARIOUS LOADS.

Current output in K-W. per hour.	Feed Water Consumption per Hour, Pounds.			
	With Superheating to about 400 Degrees Fahr.		With Extra Superheating to 465 Degrees Fahr.	
	Per K-W.	Per E. H. P.	Per K-W.	Per E. H. P.
20	48	35.8	...	....
30	39	29.1	36½	27.2
40	34½	25.7	32	23.9
50	32	23.9	29½	22.0
60	30½	22.7	28½	21.3
70	29½	22.0	28	20.9
80	29	21.6	27½	20.5
90	28½	21.3	(27)	(20.1)
100	28½	21.3	(27)	(20.1)

The results of the trials are graphically exhibited in the diagrams, herewith shown, illustrating the variation of efficiency with load and its changes with variation of superheat; the one diagram exhibiting the variation of total feed-water demand and the second showing the change of the consumption for the unit of electrical horse-power. The first illustrates the approximation to the "law" of Willans; the other the familiar curve of the common engine; while both exhibit the practical coincidence of method of variation and of actual expenditure with those of the piston-engine of good construction under equally favorable conditions of operation. It will be found, on examination of these results, that the amount of superheating required to prevent adiabatic condensation of steam, plus a small amount needed to supply the waste of heat from the working fluid through conduction and radiation from the exterior of the machine—in other words: that amount required to retain the steam in the dry, perhaps lightly superheated condition throughout its period of expansion within the turbine—is sufficient to insure this economy, and excess of superheat above this amount gives very little gain. The adiabatic liquefaction of steam and the flow of the liquid through the turbine, producing friction of notable amount, is found to be the only important reason for superheating in this apparatus, in which the expansion is necessarily adiabatic in the real as in the ideal case.

Recent trials of the Parsons' Turbine, as constructed by the Westinghouse Machine Company, in the United States, are reported to have given the following results: The engine is illus-

trated, with its connections to the generator, in the accompanying engraving. (Fig. 72.) It is rated at 500 horse-power, at 3,600 revolutions per minute.*

The steam-pressure employed was 125 pounds by gauge, the

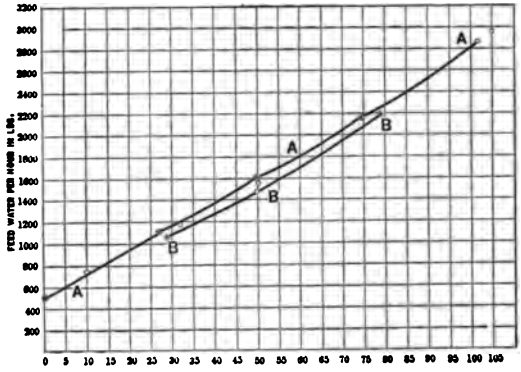

FIG. 70.—PARSONS' TURBINE.

AA—Steam superheated to about 400 degrees Fahr.
BB—Steam superheated to 465 degrees Fahr.

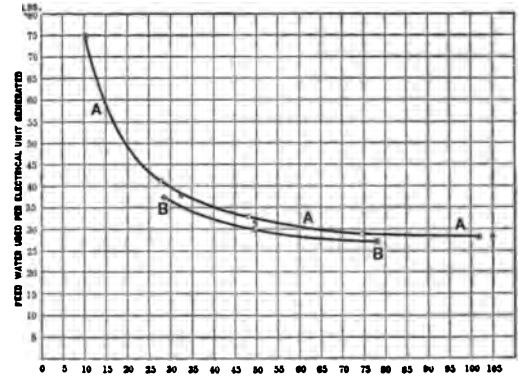

FIG. 71.—VARIATION OF ECONOMY WITH CHANGE OF LOAD.

vacuum 28 inches. The weight of the complete set, turbine and generator, is reported as 25,000 pounds, or 50 pounds per electrical horse-power. The steam was practically dry during the trials, of which the following are the reported figures, reduced to graphical form in the usual manner in Fig. 73.

* Larger sizes, up to 2,500 horse-power, are now under construction by the same builders.

The following shows the economy of steam at several important points :

Full	load	16.4	pounds	steam	per electrical	horse-power per hour.
¾	"	17.	"	"	"	"
½	"	18.2	"	"	"	"
¼	"	22.	"	"	"	"

Running light, 750 pounds steam per hour.

The diagram exhibits the same correspondence with the piston engine in manner of variation of expenditure of steam with changing load as was brought out in the earlier trials, the same

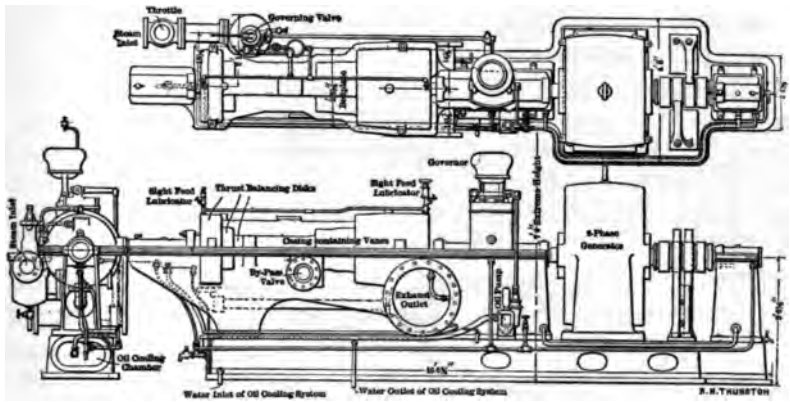

FIG. 72.

illustration of the "law" of Willans, and the same hyperbolic curve for efficiency, so generally characteristic alike of the reciprocating and rotary forms of engine; but it will be particularly interesting to observe that the loss of efficiency with decreasing loads is less marked than with the common forms of engine. Even these figures will be undoubtedly reduced by the perfection of the vacuum, and especially by such moderate superheating as may be needed to completely quench all liquefaction of steam between the boiler and the condenser and especially within the turbine.

Turbines of the compound type have been designed in various forms at Sibley College, and in some cases constructed and with some degree of success, both as to efficiency of to improved state of the applied theory of the

One of these, an axial turbine, was designed by Mr. Thomas Hall, in part while abroad taking part with the Cornell crew in the Henley races, in June of that year, and was very similar to the turbine recently brought out by Curtis. It consisted of successive disks, in each of which the jet was suitably altered in sections, velocity and direction, passing from disk to disk; *alternate disks moving in opposite directions* and thus acting each as the guide for the next; the one set keyed to a shaft turning in one direction, the other set to a drum turning in the opposite

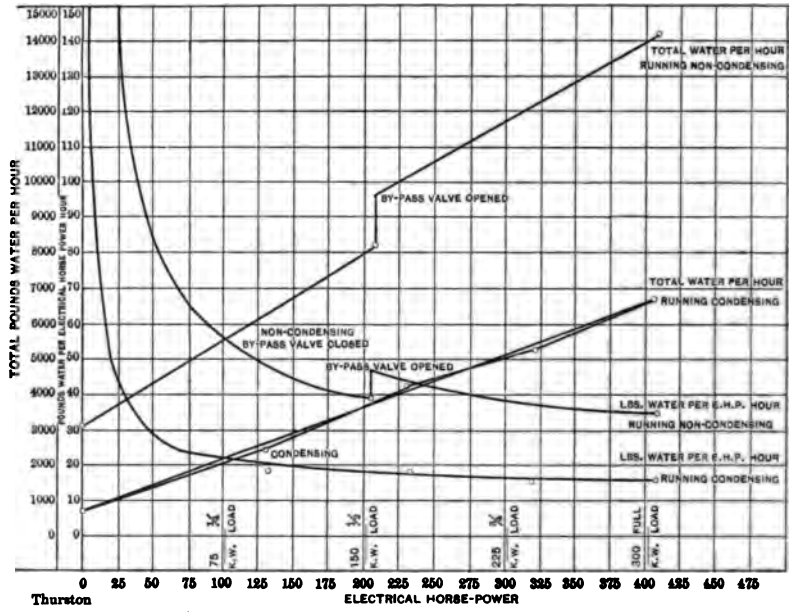

FIG. 73.—STEAM CONSUMPTION OF 500 H.P. TURBINE SETS.

direction. This device reduced the needed number of disks by one-half; only ten being used where, otherwise, twenty would have been required. The turbine was of 10 horse-power and consumed 60 pounds of steam per effective horse-power per hour at 125 pounds boiler pressure and but 14 inches vacuum; the speed being made 6,000 revolutions per minute. Steam was delivered to the turbine from the jet at atmospheric pressure and at maximum velocity of flow. A second turbine was designed by the same inventor in the following year, June, 1897, and built that year. The first was an axial, the second a radial,

turbine. In the latter, the steam was delivered through the shaft into the first of a pair of disks, revolving in opposite directions, carrying, each, concentric sets of buckets; the jet is thus taken alternately into oppositely moving buckets and the principle of the first construction is thus illustrated in the radial form of turbine. The speed, as before, was 6,000 revolutions per minute. The disks and buckets were made of phosphor-bronze. Some buckets were made by a process, since patented by Curtis, rolling bars and cutting off the length needed for each bucket. Developing 18 horse-power, it demanded under test 50 pounds of steam per horse-power-hour.

In later work, the buckets were made of an alloy of aluminium and zinc found to be particularly satisfactory for many purposes, and one which was discovered in the course of researches seeking to identify the "maximum alloy" of aluminium and zinc. It has been described already and has been frequently, generally used, in fact, in work of this sort in Sibley College, and notably in the researches of Dr. Durand on the efficiency of screw-propellers. It consists of two-thirds aluminium and one-third zinc. The corroding action of the jet of steam was too serious, however, and the buckets were later made of brass. The nozzles were made $\frac{1}{4}$-inch opening and given a taper of $\frac{9}{64}$ inch to an inch of length.

Napier's formula was tested with a straight, short nozzle with rounded entrance. Measures of impact-pressure were obtained by a series of experiments with specially constructed apparatus, and the familiar deduction was confirmed; the pressure on a bucket at rest being equal to that due the gauge pressure. With straight nozzles, the jet expands, after leaving the tube, until atmospheric pressure is reached, when it retains a cylindrical form until broken up by air-currents. In the expanding nozzle, the jet has a minimum diameter, with low pressures, less than that of the exit orifice; with increasing tensions of steam, it moved outward and located itself at a point further from the extremity as the pressure rose. The work of the turbine itself was very satisfactory.

The results of the comparison of the computed pressures of the jet, and of the estimated deliveries, with the actual work in the case in hand are shown well in the accompanying curves [illegible] laid down by Messrs. Jones and Rathbone in a [illegible] 1898.

The Laval Turbine, the modernized simple form of the Branca wheel of 1629, was brought out by its inventor about 1886, and at once took its place in the field of engineering to which this class of motors is best adapted. It became well-known to the profession in the United States through its admirable presentation at the Columbian Exhibition, at Chicago, in 1893. In 1896, it was stated that there had already been supplied to users about 23,000 horse-power of this type. It

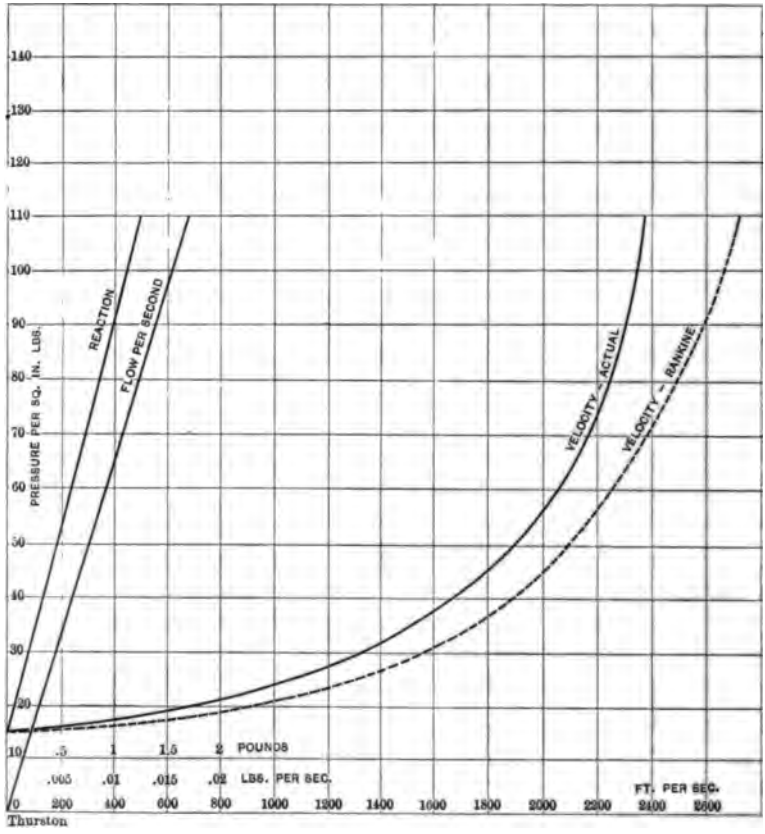

FIG. 74.—ENERGIES AND VELOCITIES OF JET-DISCHARGE.

was rapidly developed for high-pressure steam, and in 1898, the following table of consumption of dry steam per unit of time and power was published by the continental European representatives of "*La Société des Turbines à vapeur de Laval.*"

CONSUMPTION OF DRY STEAM PER EFFECTIVE HORSE-POWER PER HOUR.

H. P.	Admission pressure of that turbine in kilos par cm^2					
	6	8	10	12	16	20
	1.—*Escape to the air. Kg.*					
3	26.25	24.2	23.—	21.8	20.6	20.0
5	22.7	21.0	19.75	18.9	17.9	17.4
10	22.7	21.0	19.75	18.9	17.9	17.4
15	21.4	19.7	18.6	17.8	16.8	16.25
20	20.9	19.2	18.1	17.4	16.4	15.8
30	19.9	18.3	17.2	16.4	15.4	14.9
50	18.5	17.0	16.0	15.2	14.1	13.4
75	17.5	16.1	15.05	14.3	13.3	12.65
100 and 150.	17.5	16.0	15.0	13.95	13.25	12.55
200	16.5	15.0	14.5	13.75	12.8	12.0
300	16.25	14.5	13.75	13.0	12.0	11.50
	2.—*Escape to the condenser. Vacuum 64 cm. Kg.*					
3	18.0	17.3	16.6	16.2	15.6	14.9
5	16.3	15.75	15.3	14.95	14.4	13.8
10	14.1	13.55	13.1	12.6	12.25	11.9
15	13.55	13.0	12.6	12.25	11.8	11.45
20	11.6	11.1	10.9	10.45	10.0	9.7
30	11.6	11.1	10.75	10.45	10.0	9.7
50	10.3	9.8	9.45	9.2	8.85	8.65
75	10.3	9.8	9.45	9.2	8.85	8.65
100	10.2	9.1	8.75	8.5	8.2	7.9
200	8.8	8.4	8.0	7.8	7.6	7.4
300	8.6	8.25	7 75	7.6	7.4	7.2

Since the date of publication of this table, the steam pressure has been carried up into the thousands of pounds per square inch, one to two hundred atmospheres, and the consumption of steam and of heat and fuel per unit of time and power still further reduced. In the above table, it is to be here particularly noted that the expenditure of steam is reduced over one third by condensation, as compared with non-condensation, at all points in the table.

Tests of the 10-horse-power Laval turbine of Sibley College, with two, three and four jets in use, by Messrs. Whitfield and Wilson, 1896, gave the following tabulated results. The generator attached is rated at 6.6 kilowatts output at full load. The turbine disk is $5\frac{1}{2}\frac{3}{2}$ inches diameter, the vanes $\frac{3}{8}$ inch wide, the rim $\frac{1}{16}$ inch in thickness and the rated speed 24,000 revolulutions per minute. This gives 656 feet per second, 39,360 feet per minute; about $7\frac{1}{2}$ miles a minute, 450 miles an hour.

The turbine is geared to the generator by a reducing gearing

having the ratio 10 to 1, giving the generator a speed of 2,400 revolutions per minute. Copious lubrication was insured by the use of "sight-feed" oil cups. The vacuum was about 16 inches, except in the later runs, when it was purposely reduced to 1.3 inch at the condenser. The steam was saturated and carried some moisture. The turbine showed as good work as could have been expected from the reciprocating engine of similar capacity, and is probably capable of still better work when the form of nozzle can be perfectly identified for any stated conditions of operation, as the jet should have a specific character for each set of conditions of operation. Its "water-rate" of 46.8 pounds per horse-power hour is much better, in fact, than is usually obtained with the common engine of equal power. The best work is performed with two nozzles.

The same turbine, in a series of tests by Mr. West, in the spring of 1900, gave total expenditures of feed-water, ranging from 100 to 600 pounds per hour, delivering from zero to 10-brake horse-power, from zero to 5 kilowatts and zero to 6½ electrical horse-power; while the "water-rates" ranged from 64 to 56 per engine horse-power and from 105 to 65 per kilowatts between 15 and 50 amperes at 110 volts, the latter variations following closely the hyperbolic law.

SIMPLE IMPACT STEAM TURBINE—SIBLEY COLLEGE, C. U.

A.—2 Nozzles.

Speed, Revolutions Per Minute.	Amperes.	Volts.	Dynamo Watts Output.	Losses of Dynamo.		Engine Watts Output.
				Hysteresis and Friction.	Resistance.	
2,333	19.33	110	2,127	1,400	300	3,827
2,263	38.7	110	4,258	1,350	350	5,958
2,200	58	110	6,380	1,300	431	8,111

Horse-Power.		Output in B. T. U. Per Hour.		Pounds of Condensed Steam.			
Electrical.	Engine.	Dynamo.	Engine.	Per Hour.	Per H.-P. Engine.	Per H.-P. Electric.	Per K. W.
		A	B				
2.85	5.13	7,250	13,020	275	53.6	96.6	129
5.72	7.99	14,500	20,300	379	47.5	66.4	89
8.55	10.86	21,750	27,620	508	46.8	59.4	79.6

SIMPLE IMPACT STEAM TURBINE—SIBLEY COLLEGE, C. U.—*Cont.*

A —2 Nozzles.

British Thermal Units.				Efficiency.	
Per Hour.	Per H.-P. Engine.	Per H.-P. Electrical.	Per K. W.	Engine B/C.	Eng. and Dyn. A/C.
				Per cent.	Per cent.
322,800	63,000	113,200	151,500	4.04	2.25
446,800	56,000	78,100	104,800	4.54	3.25
597,900	55,100	70,000	93,900	4.62	3.64

B.—3 Nozzles.

Speed. Revolutions per Minute.	Amperes.	Volts.	Dynamo. Watts Output.	Losses of Dynamo.		Engine. Watts Output.
				Hysteresis and Friction.	Resistance.	
2,386	19.3	110	2,127	1,450	300	3,877
2,280	38.7	110	4,253	1,375	350	5,978
2,220	58	110	6,380	1,300	431	8,111

Horse-power.		Output in B. T. U. per Hour.		Pounds of Condensed Steam.			
Electrical.	Engine.	Dynamo.	Engine.	Per Hour.	Per H.-P. Engine.	Per H.-P. Electric.	Per K. W.
		A	B				
2.85	5.20	7,250	13,170	273	52.6	95.8	128.5
5.72	8.03	14,500	20,380	397	49.5	69.5	93.4
8.55	10.86	21,750	27,620	523	48.2	61.3	82.1

British Thermal Units.				Efficiency.	
Per Hour.	Per H.-P. Engine.	Per H.-P. Electrical.	Per Kilowatts.	Engine. B/C.	Eng. and Dyn. A/C.
				Per cent.	Per cent.
320,800	61,800	112,500	151,000	4.1	2.26
466,700	58,100	81,600	109,500	4.37	3.11
610,800	56,400	71,500	95,900	4.53	3.56

SIMPLE IMPACT STEAM TURBINE.—SIBLEY COLLEGE, C. U.—*Cont.*

C.—4 NOZZLES.

Speed. Revolutions per Minute.	Amperes.	Volts.	Dynamo. Watts Output.	Losses of Dynamo.		Engine. Watts Output.
				Hysteresis and Friction.	Resistance.	
2,352	19.3	110	2,127	1,410	300	3,837
2,260	38.7	110	4,253	1,350	350	5,953
2,238	58	110	6,380	1,325	431	8,136
2,218	58	110	6,380	1,300	431	8,111

Horse-power.		Output in B. T. U. per Hour.		Pounds of Condensed Steam.			
Electrical.	Engine.	Dynamo.	Engine.	Per Hour.	Per H.-P., Engine.	Per H.-P., Electric.	Per Kilowatts.
		A	B				
2.85	5.14	7,250	13,050	308	60	108	144.5
5.72	8.02	14,500	20,300	428	53.4	75	101
8.55	10.9	21,750	27,700	567	52	66.4	88.8
8.55	10.86	21,750	27,620	618	57	72.2	97

British Thermal Units.				Efficiency.	
Per Hour.	Per H.-P., Engine.	Per H.-P., Electrical.	Per Kilowatts.	Engine. B/C.	Eng. and Dyn. A/C.
				Per cent.	Per cent.
360,100	70,100	126,300	169,200	3.63	2.01
497,600	62,100	87,000	116,700	4.08	2.92
661,200	60,700	77,400	103,600	4.2	3.3
728,600	67,000	85,300	114,000	3.8	2.99

The form of the Laval turbine is seen in the accompanying sketches, of which the first exhibits the form of the 10 horse-power, 6.6 kilowatts, set, the tests of which in Sibley College are elsewhere reported.

The details of the construction of this simple turbine are seen in the following illustrations, in which the section of the nozzle and of the rim of the disk of the turbine permits an excellent and very clear representation of the process of energy conversion here carried on in the impact turbine. Three jets are shown, but the number may be made greater or less, as may be found in any individual design best. The wheel evidently belongs to the class of " partial turbines," as the hydraulic motors of this type have been called. The succeeding figures show the form of the gears, the turbine disk, and the nozzle separately. One important and peculiar feature of this turbine is the adop-

tion, by its inventor, of a slender, flexible shaft which can spring sufficiently to permit the disk to whirl about its centre of gravity, a point which never precisely coincides with its centre of figure; this expedient allows of complete avoidance, in a well-made turbine, of the jar otherwise produced.

Trials of a similar Laval turbine reported by Professor Goss to the American Society of Mechanical Engineers * give figures as in the following table:

RESULTS OF TESTS, LAVAL TURBINE.

Nozzles.	Number of Test.	Revolutions per Minute of Belt Wheel.	Brake Horse-power.	Steam Pressures by Gauge.		Total Pounds of Steam per Hr.	Pounds of St'm per Brake Horse-power per Hour.
				In Boiler.	In Engine below Governor Valve.		
All four nozzles in action, three having a diameter in throat of 0.138 inch and one a diameter in throat of 0.157 inch..	1	2,138	0.00	130	17.1	120.8	.....
	2	2,545	1.63	130	42.2	210.3	128.6
	3	2,038	2.36	130	48.5	230.8	99.8
	4	2,118	2.97	130	55.6	254.6	85.7
	5	1,917	3.46	130	61.9	275.5	79.6
	6	2,072	4.38	130	70.8	313.0	71.5
	7	2,128	5.10	130	76.9	328.5	64.4
	8	2,576	7.52	130	99.6	403.0	53.6
	9	2,453	8.24	130	104.4	422.8	51.3
	10	2,411	10.33	130	126.3	491.8	47.8
Three nozzles in action, two having a diameter in throat of 0.138 inch and one a diameter in throat of 0.157 inch..	11	2,584	0.00	130	31.3	121.4	.....
	12	2,112	3.95	130	83.6	267.8	67.8
	13	2,125	4.77	130	93.4	286.0	60.0
	14	2,490	6.50	130	111.7	346.3	53.3
Two nozzles in action, each having a diameter in throat of 0.138 inch	15	2,546	0.00	130	42.2	99.3	.....
	16	2,049	1.95	130	83.5	162.6	83.4
	17	1,909	3.43	130	121.1	222.9	65.0
	18	2,412	3.87	130	127.0	229.6	59.3

The lowest figure here obtained is 47.8 pounds of feed-water per horse-power per hour delivered upon the brake, which corresponds to about 43 pounds per indicated horse-power with the reciprocating engine.

The results of trial of a 50-horse-power Laval turbine are reported by Professor Cederblom, of the Polytechnicum at Stockholm, his assistant, Mr. Anderson, and the inspector of the Board of Trade of Stockholm, Mr. Uhr, May, 1893, follow.

The test continued for 8 hours, from 9:45 A. M. to 5:45 P. M., during which time 617.5 kilograms South Yorkshire coal and

* *Trans. A. S. M. E.*, December, 1895, vol. xvii., p. 81.

4.651 kilograms feed-water of an average temperature of 15.4 degrees Celsius were consumed. The effect was determined by brakes; the number of revolutions was 1,645 per minute. The steam was obtained from a fire-box tubular boiler, at a pressure of 8.6 kilograms per square centimeter above the atmosphere. The motor was close to the boiler. In the steam piping, between the boiler and the motor, a water-separator was inserted.

The steam pressure was determined by a manometer, placed between the throttle-valve and the turbine. This pressure varied between 8.6 and 7.6 kilograms per square centimeter.

The pressure in the exhaust-pipe was constant during the

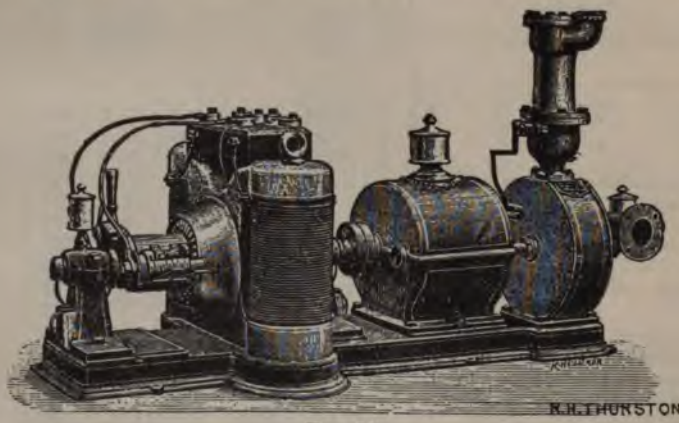

FIG. 75.

whole test at 0.12 kilogram per square centimeter absolute pressure.

The exhaust steam was condensed by an ejector condenser, fed by a centrifugal pump, driven by another motor which obtained steam from a separate steam boiler. The circulation water was warmed up by the steam from + 7 degrees to + 16 degrees Celsius.

During the trial, the turbine developed 63.7 effective horse-powers, with 8.95 kilograms steam, 1.2 kilograms coal per horse-power per hour. Later tests reported at the Paris Exposition, 1900, for a 300 horse-power turbine of this type gave as low as 63 kilograms steam.

These figures, corresponding to 19.7 pounds of steam and 2 66 pounds of coal per horse-power per hour, at the brake, may be accepted as again exhibiting the capacity of the turbine, prop-

erly operated, and its promise as a rival of the common forms of even good engines where, as here, employing 108 to 122 pounds steam pressure and with a vacuum of 26 inches. The gain progresses, in the steam turbine, with increasing loads up to the limit of power of the machine; in which respect it de-

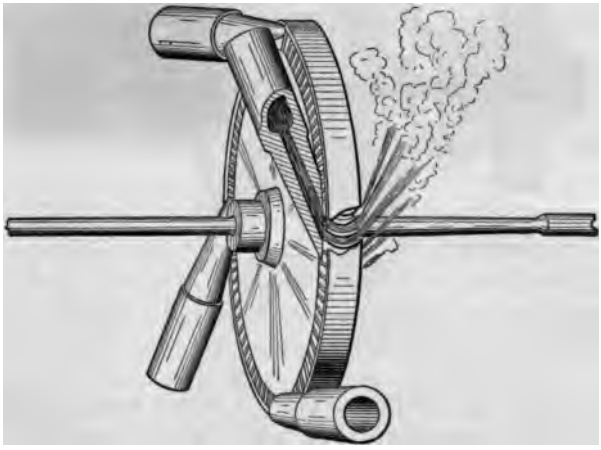

FIG. 76.

parts markedly from the case of the common forms of engine. In the steam turbine, there is no overload except as fixed by its maximum power, and its rated best load and its maximum capacity are identical. (See *Note IV.*, appended.)

Some 10 years ago a steam turbine was built in the shops of Sibley College and reported upon by Messrs. J. C. Brown and W. B. Lachicotte. It was made a "compound" or series tur-

FIG. 77.

FIG. 78.

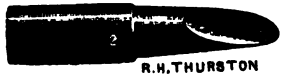

FIG. 79.

bine, of the Dow form (Figs. 80, 81), with steam passages through stationary guides and systems of vanes in alternation, the general direction of flow being radially outward, thus taking advantage of the enlarging areas of section to meet

the requirements of the expanding steam. The annular spaces between guides and turbine passages form reservoirs and feeders, and equalize pressures throughout the annulus Com-

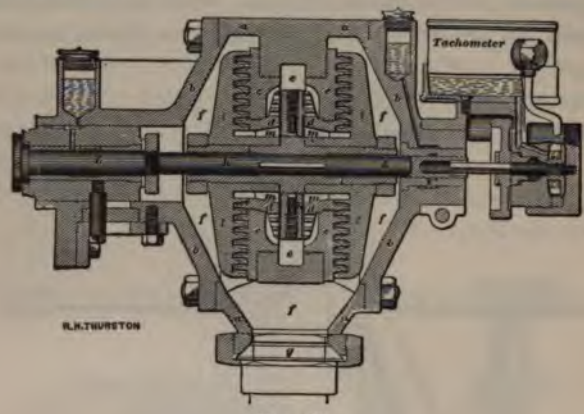

FIG. 80.

pounding, with the steam turbine, is thus a vastly more simple and satisfactory operation than with the reciprocating engine, and this is particularly true of the outward-flow series type. Its purpose obviously, however, is altogether different in the two

FIG. 81.

machines. The turbines are not subject to "cylinder condensation," and are compounded only to secure at once, satisfactorily, complete expansion and reduced speed of rotation; their speed is, at best, too high for general purposes in engineering.

In this machine, the frame and the end covers were of cast-

iron and the disks of aluminium bronze, to the conductivity of which no objection arises in this type of motor. The number of passages in the wheel was 10 at the axis, increasing to 13 in the next set of vanes, 16 in the third, and thus up to 26 at the periphery of the machines, while the guide passages ranged in number from 26 to 56. The guide passages made a constant angle of 95° with the turbine passages, at entrance, and the latter, at the

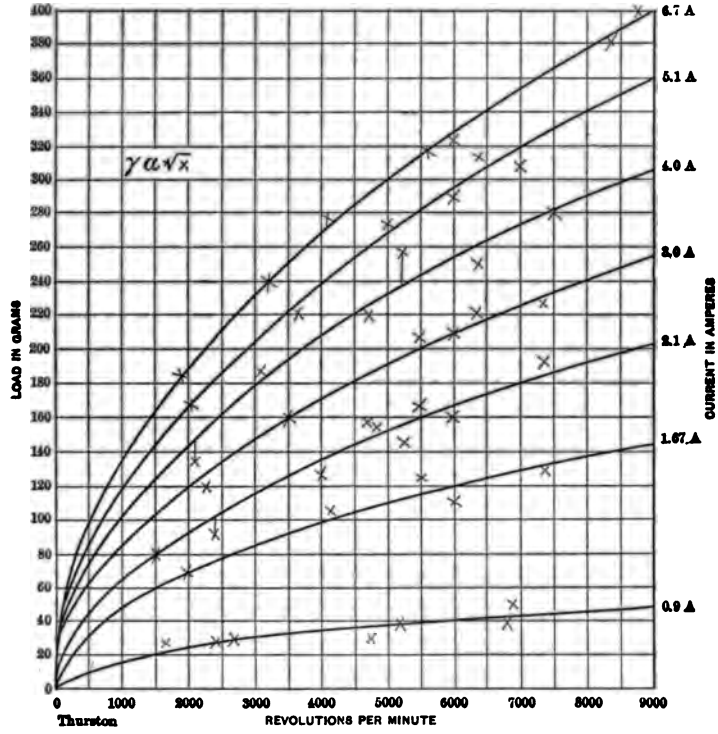

FIG. 82.—RESISTANCE OF MAGNETIC BRAKE

exterior of the wheel, were set as nearly tangent as the construction permitted. Accuracy of construction to within 0.001 inch was required. The speed of revolution was made 21,000 per minute and, at this speed, the effort of an unbalanced mass of one-pound weight would be, at the circumference of the turbine, 37,500 pounds. The stress on the disks at this speed was computed as 14,000 per square inch of metal. The tenacity of the latter was about 70,000, as determined by test. The flywheel was 5.57 inches in diameter and weighed 13.2 pounds. Its en-

ergy is 477,160 foot-pounds at 10,000 revolutions a minute. The turbine would spring it up to that speed in one minute; thus exerting 14.5 horse-power as a mean or 29 horse-power as a maximum and its rated power. Turbines of this construction were reported to demand from 20 to 50 pounds of steam per horse-power per hour. This machine had a diameter of disks of 6½ inches and a depth of passage of about a half inch.

Messrs. Johnson and Mott made a magnetic brake with which to test this turbine, spinning a disk of steel between a pair of powerful magnets and relying on the work of production of Foucault currents to provide resistance. The brake was coupled directly to the engine shaft. It was found that this resistance varied as the square root of the speed and the curves on the speed-load diagram were parabolas. The power absorbed varied as the square root of the current and as the square root of the number of ampere turns active in producing the magnetic field.

In this brake, the use of water to hold down the temperature of the disk was of course necessary, and the resistance of the water to acceleration conspired with that of the dynamometer proper to produce total resistance. In later experiments at high speeds of rotation, a simple disk running in still water, and water renewed only as required for cooling, was employed very successfully.

Professor Kennedy, testing a Parsons turbine with steam superheated to various degrees, found the consumption of steam per electrical horse-power per hour, with 97 pounds steam pressure, 14 inches vacuum, developing from 37.5 electrical horse-power to 164.9, to vary from a maximum, 32.9 pounds at the smallest power and with 20 degrees Fahr. superheat, to 23.3 at 92 electrical horse-power with 37 degrees Fahr., to 20.8 at 148.5 electrical horse-power and 67 degrees superheat, and to 20.3 pounds at 165 electrical horse-power with 55 degrees superheat; but just how the gain is to be apportioned between that due to increasing delivery and to increasing superheat is uncertain.

Rateau reports the results of about forty experiments with a turbine having a disk thirty centimeters in diameter (12 inches, nearly), selected, as he states, from thousands, in which the total efficiency, the ideal taken as unity, ranges, for engine and dynamo attached, from three to four tenths, averaging about 0.375, with initial steam pressures of about eight atmospheres, back-

pressures one atmosphere, revolutions 6,000 and consumption per kilowatt hour of 25.3 kilograms. The highest figures for efficiency are 0.408, with ten atmospheres steam pressure, one-third atmosphere back-pressure, 18,000 revolutions, and 16.5 kilograms (35 pounds) per kilowatt hour. The voltage was usually about 100, the amperage rose, in the case last cited, to 342 with 118.5 volts, 40.6 kilowatts. The best results were secured with two nozzles. By total efficiency is here understood the ratio of electric energy developed by the dynamo to the total energy computed as available in the steam supplied. Plotting the speeds and efficiencies of this turbine, it was easy to ascertain the influence of the former upon the latter, and it proved that a higher speed, 21,500 revolutions, would have been better than the speed actually adopted with this individual machine and would have given a total efficiency of 0.45, more than ten per cent. of its own value higher than the best figure attained during the series of trials reported. This would have given a speed of periphery of about 325 meters per second, 1,066 feet per second, 63,960 feet per minute, 700 miles an hour nearly.

The efficiency of the turbine, apart from its driven mechanism, the dynamo, in this case approximates in the assumed case 50 per cent. that of the ideal, reckoned from efficiency unity for heat transformation. This is equivalent to saying that the steam-turbine, in this case, demands twice as much steam as its ideal prototype, the perfected steam-engine working in the Rankine-Clausius cycle. This, in turn, means wastes of one-half of the heat supplied and probably in some such proportion as this: friction of journals and of fluid, 10 per cent. each, 20 per cent., conduction and radiation 10 per cent., leakage 20.

The Curtis Steam Turbine, a more recent invention, is to be classed with the axial turbines and is a compound wheel. A pair of wheels turn on a single shaft, the one taking steam from a nozzle suitably adjusted and conducting the steam from the steam-pipe and boiler to the turbine; the other taking the expanded steam rejected from the first turbine and still further reducing its pressure while it expands to the lower limit of tension and higher limit of volume, at this limit discharging it into either the atmosphere or a condenser. The intermediate guide-curves are mounted upon a fixed disk, set between the two revolving turbine-disks. By thus compounding, this turbine, like other compound machines, is adapted to a comparatively low

velocity of rotation. The novel feature of the machine, as disclosed by reference to the patent-drawings, is seen to be a peculiar and ingenious form of nozzle which permits the adaptation of the steam-supply to the requirements of the load, by the automatic action of the governor, at a constant and maximum initial tension, thus avoiding throttling and permitting the maintenance of boiler-pressure, approximately, and the complete utilization of the thermodynamic advantages of full boiler-pressure and most complete expansion. The delivery of steam may also be made to take effect at several vanes in a group, and some reduction may be thus effected in the leakage waste.

Reported tests of this turbine give a performance, at a steam-pressure of 130 pounds by gauge, and with a vacuum of 28 inches, of 24 to 27 pounds of steam per horse-power-hour, measured by the break, and at 2,800 revolutions per minute, with powers ranging from about 125 down to 40, non-condensing, figures are given as 35 to 45, between 180 and 60 horse-power, as compared with a probable 20 to 45 pounds of feed-water under similar ranges of condition for the reciprocating engine. Its weight is about one-fifth that of the latter at similar powers, and it has about one-tenth the volume.

The Effect of the Presence of Water in the Steam Driving a Steam Turbine, thermodynamically, is practically *nil*. This is shown both by a study of the form of the expression for thermodynamic efficiency of the type-cycle, in which it is evident that no ordinary amount of moisture, at least, could affect its value, by the examination of the expansion-curve, in the cycle, which is the only part of the cycle affected by the introduction of water with the steam, and also, and more convincingly, by direct experiment.*

That the removal of moisture from the steam and the provision of superheated steam effects an important gain in the steam turbine has been known from the earliest work of Professor Ewing made with this comparison in view. What the method of gain is, however, may not be so easy to see, when it is

* Professor Jacobus has shown this fact by direct experiment and frequent experiments, direct and indirect, on other forms of heat-motor, on record in the transactions of the *A. S. M. E.* and elsewhere, prove that, while the slightest amount of superheat produces a relatively important gain, the quality of really wet steam may greatly vary without perceptible variation of efficiency, whatever the type of engine.—*Trans. A. S. M. E.*, 1897, vol. xviii., p. 699.

understood that it cannot be a thermodynamic gain of any large amount. That a gain in capacity may be secured by superheating has probably not been realized by the average practitioner, even though familiar with the principles and practice involved in the production of the steam turbine of high efficiency.

Comparing the reported efficiencies of the steam turbine with the ideal efficiency of the representative cycle, it is seen that there is a large discrepancy to be accounted for, as large as in the case of the ordinary engine;* while it is equally evident that it cannot be attributed, as in the piston engine, mainly to internal condensation due to varying temperature of metal in contact with the working fluid. Thus, in the turbine operating with one hundred pounds boiler pressure and with a vacuum of 26 inches, corresponding practically to two pounds back-pressure, absolute, the demand for steam with complete expansion should be about 10 pounds of steam or feed water per indicated horse-power, and about 10,000 British thermal units per unit of work and time; while the best work of the real steam turbine is about double this quantity for similar conditions, so far as obtainable. One-half the power-equivalent of the heat supplied in the steam is thus lost. This loss cannot have occurred through the action of "cylinder-condensation"—which might account for it in a wasteful steam engine of the common type—but must be traced to *either* enormous friction or equally remarkable waste by leakage or by conduction and radiation. The latter, however, must be less than in the piston-engine; for the new motor is much smaller and has smaller radiating surfaces for similar heat expenditure and power-development. Leakage might readily account for such losses and more; but a well-made steam turbine need not be subject to this waste in very extraordinary degree. The one remaining possible source of serious loss of power is friction. The friction of rubbing is comparatively small and can be readily ascertained with a fair degree of accuracy, as it is comparable with that of the cotton-spindle. The waste is not at that point; it apparently can only be fluid friction and that may be very large at speeds of relative motion of surfaces between which water may be caught, such as exist in the steam turbine. It

* *Trans. A. S. M. E.*, No. 832, 1899, vol. xxi., p. 185.

is probably, therefore, fair to assume that we have found a main cause of the difference between the efficiencies of the ideal and of the corresponding real steam turbine: fluid-friction, friction of water carried into, or produced by, condensation caused by exit of heat from the machine.

Two essential conditions in operating the steam turbine are thus found to be required to insure the highest efficiency of the steam turbine. These are obvious thermodynamic requisites, but their advantage in this case is not all, or even, in the case of one of them, certainly, mainly due to thermodynamic gain. They are (1) the use of superheated steam, (2) the employment of a good condenser and a minimum back-pressure.

The reason of the importance of these conditions, and of their effectiveness in securing a good performance with any given machine, is the extreme susceptibility of this form of motor to friction-wastes of energy and loss of efficiency through seemingly minute resistances.

The influence of friction in producing wastes of energy in a fast-running machine are at once realized and appreciated when it is considered that the work thus wasted is the product of a resistance into a distance, and that, in the case of the steam turbine, the velocity is enormously greater than that of the performance of work in any other motor. The factor of that lost work represented by the resistance, at any given value of the product $R \times V$, is reduced in proportion to this magnified speed.

A steam turbine of ten inches diameter is operated regularly at 20,000 revolutions a minute; its velocity of periphery is thus about ten miles a minute, 600 miles, 500 knots, nearly, an hour. In the formula for horse-power of vessels, calling V statute miles,

$$I.\ H.\ P. = S\ V^3 / 20{,}000;$$

for unity of area, $S = 1$, this gives the horse-power to drive one square foot of area through water at 500 nautical miles an hour, as

$$I.\ H.\ P. = 500^3/20{,}000 = 6{,}250\ H.\ P.;$$

above 6,000 horse-power to drive one square foot through water at the rate at which the periphery of the steam turbine sometimes moves. One of our recent transatlantic steamers would demand 320,000,000 horse-power at this speed.

Assume a drop or a film of water to lie between the disk of

the turbine and the casing, and to act in resistance as does water on the surface of a ship in motion, the film to have a superficial area of one one-hundredth of a inch; the resistance would be the above figure, 6,250, divided by 14,400, nearly one-half of a horse-power for each drop. Assume a thread of water in the steam turbine, between wheel periphery and casting, having the measure, 0.001 inch width and 31.416 inches length, 0.03 square inch area; its resistance under these conditions would be about one and a half horse-power.

Assume a drop of water, one-tenth of an inch in diameter, to drip from the casing upon the wheel and thus to take up energy otherwise transferred for useful work. The energy wasted would be the product of the weight into the half-square of the final velocity, $\frac{1}{2} m V^2 = \frac{1}{2} w V^2/g$; or, in feet, seconds, pounds and foot-pounds, the loss per minute is

$$E = 120 \text{ foot-pounds, nearly,}$$

or practically one horse-power per each 275 drops, at the periphery of the wheel. It is possibly the fact that drops could hardly fall upon the wheel in such manner and numbers as to produce so important an effect; since the drops are usually carried on with the stream of motor fluid and bring energy into the turbine, which may be surrendered to the motor rather than absorb energy from it; but yet there is more or less of friction of the kind here discussed, and some action of the kind just referred to, undoubtedly, occurs. What is sought here is simply to impress upon the mind the enormous influence of friction upon the steam turbine in reduction of its efficiency. Even the shaft-bearings have a rate of waste of power, due their high velocity of rubbing surfaces, that would hardly be anticipated by one who had not looked into that matter.

Assume a shaft one inch in circumference at the journal, spinning at the rate of 20,000 revolutions per minute, and its friction to be one-fourth as great as if running in water; then the length of journals being total, two inches, the area of rubbing surface would be 0.014 square foot; its velocity is 1,666 feet per minute; its resistance, on the basis assumed above, would absorb nearly a fifth horse-power. Precisely what is the friction of the lubricated journal at these speeds is not known; but its resistance would undoubtedly follow the law of increase with speed illustrated by all fluids; the deduction following

that, with the steam turbine, the necessity of insuring minimum friction of journals, as well as of disk rotation within the atmosphere of vapor, air and rain, or mist, or which surround it, is vastly more imperative than in the case of ordinary machinery of comparately low speeds of moving parts.

The cream separator and other "centrifugals" are admirable, as affording opportunity to employ the peculiar form of motor with which we have here to deal. They are speeded up to 5,000 or 10,000 revolutions per minute; and even the reaction steam wheel of Hero may do very good work with them in competition with the small and wasteful steam engine of reciprocating type constituting their alternative. Standard speeds are 6,000 to 7,500 revolutions per minute, and a common performance gives about 3 horse-power per 1,000 pounds of milk separated in ordinary creamery work.* Some, however, are far more efficient than others. The steam consumed in reported trials is given as 40 pounds per horse-power hour, which is much below the consumption of the average steam engine of similar power—say, 3 to 5 horse-power.

When it is considered that at a not unusual speed of periphery of the disk of the centrifugal, 6,600 feet per minute, the impulse factor for 1 horse-power is but $33,000/6,600 = 5$ pounds, and that for the range 25,000 to 50,000 feet per minute, which may be taken as that of the working of the steam turbine in commercial sizes, it is as low as from 1.3 to 0.66 pound at the radius of the wheel, it is easily realized that the slightest friction, whether of solids, of fluids, or "mediate," must sensibly affect efficiency. It is thus easily understood that even the friction of the air or the atmosphere of vapor surrounding its whirling disk, the touch of a drop of water, or the presence of a film or a thread of water in the capillary space between the disk and the casing or between two adjacent disks, may seriously affect its economical operation and that of any high-speed machinery driven by this prime mover.

Velocities of from 5 to 10 miles a minute, 300 to 600 an hour, are as difficult to appreciate and understand as to deal with in this construction. The work constitutes a new department of mechanical engineering. The flow of the steam into the pas-

* "Test of Cream Separators," by H. H. Wing, *Cornell University Bulletin*, No. 66, May, 1895, p. 173.

sages of the steam turbine at the pressures, now usual, of 150 pounds per square inch, absolute, approximates 3,000 feet per second, 180,000 feet (nearly 35 miles) a minute, 2,100 miles an hour, and the minimum velocity of periphery of the simple turbine of the Branca type, for the ideal and perfect machine, should be one-half this figure, and for the Hero type, infinity. To meet this demand the engineer must employ metal capable of safely withstanding a stress of great magnitude, even for the Branca turbine; and he can never operate a perfect Hero engine at its speed of maximum efficiency, although, fortunately, the loss of efficiency down to attainable speeds is comparatively small.

Conclusions follow from what has preceded, which bear directly and in an important manner upon the principles of design of the steam turbine and its operation as a source of power:

(1) The steam turbine thermodynamically approximates in its real form more closely to the ideal than does any other type of heat motor. Its cycle lacks only the introduction of the Carnot compression.

(2) It is entirely free from that waste, which in the real steam engine of common type constitutes usually, if not invariably, the most important of its extra thermodynamic losses.

(3) It is peculiarly well fitted for use with those very high steam pressures as we now regard them, which must ultimately probably be resorted to by the engineer designing heat engines in his endeavor to further improve the efficiency of that class of motors.

(4) It is only limited in speed of rotation by the strength of its materials of construction.

(5) It is especially suitable for use with superheated steam, it having no rubbing parts on which lubrication may be difficult in presence of superheated steam, and the limit to the superheat, so far as the motor is concerned, being only found at that point at which increased temperature of metal produces reduction of tenacity in objectionable amount. That limit, not as in earlier days of lubrication with animal oils, and still with other engines, is fixed with this machine at the boiler.

(6) As to its operation: it is obvious that friction is peculiarly active for evil in this motor, and that small diameters of journal, freedom from contact of part with part, except as absolutely

required by the construction, and minimizing fluid friction by superheating steam, and by securing as complete removal of the atmosphere, air, or vapor from about the revolving wheel as practicable, must be carefully sought in order that the mechanical efficiency of the machine shall be made a maximum.

(7) The wastes of the steam turbine are all extra thermodynamic; the loss due the absence of adiabatic recompression excepted. They consist of (1) journal friction, which is made a minimum by the use of a flooded bearing and a light ungent; (2) fluid friction between disk and leakage steam, or suspended moisture in the jet, which may be made a minimum by superheating, and between the disk and its enclosing atmosphere of vapor, which may be minimized by the employment of a good condenser; (3) loss of heat and of steam by leakage, which may be reduced to a minimum by durable material, fine workmanship, and close fits; (4) waste by incomplete expansion, which may be reduced to a limit determined by the finance of the case, by the resultant increase of friction and of cost due the necessary enlargement of the turbine; and, finally (5), thermodynamic waste by failure to secure that complete adiabatic recompression of the fluid which is necessary to convert the Rankine-Clausius' cycle into that of Carnot. The latter is a peculiarly difficult matter with the steam turbine, since it probably necessarily involves the employment of a separate vapor-compression pump of special character, and an amount of added work and cost which may introduce losses more than compensating its gains.

Summarizing:—The steam turbine should be operated with steam of maximum safe pressure, at a constant and suitable speed, with superheated steam and good condensation. Under variable load, the "partial" turbine construction or its equivalent should be adopted, and the power adjusted to the load by variation of the steam supply by the governor, in such manner as to permit its action in correspondingly varying quantity at constant initial pressure, and with always complete expansion, and with constant speed. Where, as in marine engineering, the turbine drives a load varying with necessarily varying speed, the endeavor should be made to secure a constant speed of steam turbine while permitting varying speed of screw shafts.

NOTES.

I.—The Avery Engine.

William Avery's steam turbine, a reaction wheel of the Hero type, as built at Syracuse, N. Y., prior to 1833, had a diameter between the orifices of 3 feet, and a speed of 3000 revolutions per minute. Several of his engines were in operation in 1835, and "to the entire satisfaction of those who use them," according to the *American Mechanic's Magazine* of 1835. Mr. N. Felt, of Cicero, N. Y., reported May 1, 1835, that the turbine driving his sawmill, built by Messrs. E. Lynds & Son of Syracuse, an Avery steam turbine, demanded two-thirds the quantity of fuel for-

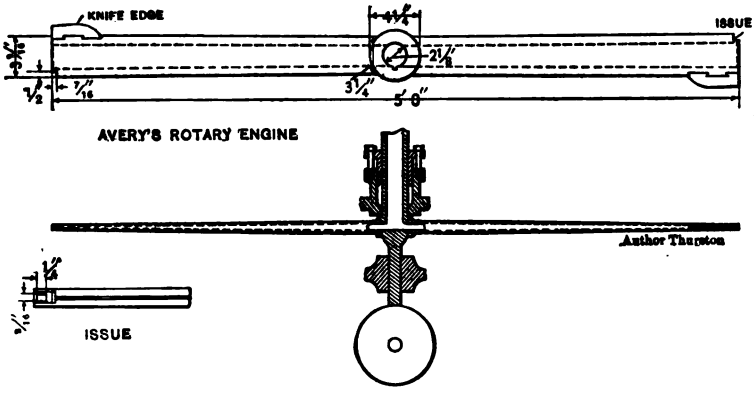

FIG. 88.

merly consumed by the reciprocating piston engine which it had displaced.

I am indebted to Prof. J. E. Sweet, past-president of the American Society of Mechanical Engineers, for the following:

"The figured drawing is from an engine still in existence. The arm is made, with the exception of the end-pieces and knife-blades, of two pieces of iron brazed together from end to end at the edges. The issues (as Mr. Avery designated them) are $\frac{1}{8}$ inch by $\frac{1}{4}$ inch each. The amount of steam that would flow through these insignificant orifices was enormous, and no doubt from the reason pointed out by Professor Webb that, at the enormous velocity the arms acquired, centrifugal force added greatly to the pressure at the outlet. If this is true, as it must be, then this comes the nearest to self-created force of anything

in mechanics. The speed of the tips of the arms of a 7-foot rotary placed upon a locomotive, in 1836, which was put upon a railroad near Newark, N. J., and ended its life in a ditch, is stated in Mr. Avery's notebook to have been at one time $14\frac{1}{4}$ miles in a minute. The additional pressure due to centrifugal force of a 5-foot arm moving at 10 miles a minute would be, if no mistake has been made in the figures, something like 9,000 times the weight of the body, so that, even though steam is light, its pressure would be greatly increased over that due to boiler pressure.

"The difficulties met with were the end-pressure on the hollow shaft, which was overcome by running the end of the shaft against the edge of a wheel set at right angles. The trouble in setting up the packing around the hollow shaft, as a little extra friction, became a large factor, and the fatal thing was that the knife-edges at the ends of the arms coming in contact with the steam issuing from the opposite arm, it cut them away so as to require too frequent renewal. Noise, too, was an objection. The economy of the engine was about the same as the common slide-valve engines; for when slide-valve engines were substituted for them they could saw no more lumber, but made less noise and avoided having to send them to the shop every two or three months to have the knife-edges renewed.

"There has been a conviction in the mind of the writer for thirty years that an expanded nozzle at the issues would give the benefit of expansion, and the expanded nozzle of the De Laval engine confirms this notion. With this improvement, the use of a mechanical fit in place of stuffing-box, and with the adoption of modern methods to deaden the noise, it is likely the Avery engine could be made to rival the De Laval, and possibly the steam turbine; but even then the high-speed rotary requires a troublesome reducing motion and lacks a governor to make it rival the reciprocating engine."

II.—Comparative Efficiencies.

In any form of impulse-wheel, whether the fluid be liquid or gaseous, a maximum efficiency will be attained when the velocity of the stream at entrance upon the wheel is a maximum, the entrance smooth and without disturbance of the flow, the motion through the wheel-disk smoothly retarded, and the rejection

effected at minimum velocity, without further expansion of volume in the case of the vapor or gas, and without other motion of the rejected fluid than that of the jet as a whole. For efficiency unity, the entering stream must have the maximum velocity due the head, the final velocity with respect to the earth, both as a mass and in its interior elements, being made zero. This is evidently impracticable, but losses aggregating more than 10 to 20 per cent. may be avoided, in best practice, where the design, the construction, and the operation are alike good.

Could such perfect development of kinetic energy be secured, and as perfect utilization by its absorption in the wheel, the following would be approximately the efficiencies for fluids expanding from seven atmospheres to one, or for liquids falling from altitudes corresponding in their equivalent pressures, the back-water level, in the latter case, being taken as 32 feet below the point of discharge of the water, for the hydraulic machine—a comparison only fair for our present purposes:

IMPACT-WHEEL EFFICIENCIES.

Water, between 234 feet head and 32	0.143
Steam, between 7 atmospheres and 1	0.142
Carbon disulphide	0.181
Ammonia	0.143
Ether	0.154

III.—VARYING LOADS AND EFFICIENCIES.

A serious fault of the common turbine, for many places and purposes, is its defective efficiency at low or irregular speeds, and especially where lower speeds than that appropriate to the design must be adopted for any considerable proportion of the working time. Experience with the steam turbines driving the *Viper* shows that, at 15 knots, one-eighth full power, they have not full-load efficiency. This is apparently an inherent defect, coming of the necessity of adjusting the speed to the velocity of flow of the steam, of the comparatively small variation of that rate of flow with varying pressures, and of the rapid departure of the value of its efficiency from its maximum with any variation of velocity from the best speed. At two-thirds power and 31 knots, however, the fuel-consumption fell below the guarantee, 2.5 pounds.

The case is, in this respect, precisely that of the hydraulic

turbine, which sometimes consumes nearly as much water at part-gate as at full-gate, while the best often lose 50 per cent. of their maximum efficiency, notwithstanding the fact that the water wheel usually maintains a constant speed. Were the speed also to vary, as is necessarily the case in marine engines with reduced powers, the loss would be in still larger proportion. With turbines driving machinery in mills and factories at a constant speed, as is almost universally the case, the efficiency has been found to drop from 80 per cent. to about 20, the load falling from its maximum to 15 per cent. or less of that figure. At half load, the efficiency often ranges near 50 per cent., the maximum at full load being 80. Some such variations must be expected with the ordinary steam turbine. In the case of the stationary engine, special designs, as of "partial turbines," may permit some evasion of this loss by adjustment of the number of working jets and passages to the demand for work; but this is less readily accomplished at sea, for example, where the reduced load also means lower speed.

The steam turbine, however, has been so well adapted to this case that Mr. Parsons reports the following figures for uniform speed in an electric lighting set.*

PART-LOAD EFFICIENCY OF STEAM TURBINE.

	k. w.	lbs. steam per k. w. per hr.
Overload	1,250	18.9
Full load	1,000	19.9
Three-quarters load	750	21.5
Half load	500	24.3
Quarter load	250	32.1
No load	0	—

The steam-pressure was 130 pounds at the engine, and the steam was superheated 18 degrees Fahr. The best of the reported figures corresponds closely to 12 pounds per indicated, and 13 pounds per brake horse-power, according to Mr. Parsons, who thinks it perfectly practicable to design a steam turbine outfit that will satisfactorily drive at all required speeds and with comparatively small variation in efficiency, competing in this respect with the ordinary type of engine for similar service.

* *The Engineer*, London, November 20, 1900, page 444.

IV.—Designing Guide-Curves and Passages.

The process of designing the guide-curves and passages of the steam turbine should begin with the proportioning of the nozzle, which should be so designed that it will receive the proposed quantity of steam at initial pressure, permit its expansion, as nearly as practicable in the manner and at the rate necessary to secure the continuous transformation of its stored energy into the work of acceleration, from initial to final delivery pressure, smoothly and without eddies or abrupt changes of either direction or section, until it delivers the steam, in a compact jet, at the right point and in the right direction, at the point of reception by the wheel.

The wheel passages should be so designed that the jet may be received into them at the section of stream and specific volume of fluid at which it leaves the nozzle, may be smoothly guided through the arc required, and with continuous reduction of velocity, until, on leaving the passage, it is brought down to the proposed minimum velocity of discharge and into the intended direction, with minimum energy with respect to the earth and with the proper flow relatively to the wheel.

The most systematic and scientific method of laying down these paths through the jet and the wheel is that of plotting the path of the jet in space—its line, its velocities, and variations of section being determined from its entrance into the jet to its discharge from the wheel. This being accomplished, it can be seen just how far the designer can go in the direction of reversal of the motion of the jet while in the wheel, and just what clearances must be allowed. The path relatively to the earth being thus determined, and the motion of the wheel being known, it becomes possible to lay down in a somewhat similar manner the path of the stream relatively to the wheel-disk, and thus to ascertain the proper shape of the passages across the disk. With hydraulic turbines some latitude is permitted in assuming the laws of acceleration and of retardation of the inelastic fluid with corresponding modifications of the forms and proportions of section of the wheel passages; but this is in less degree true of the perfectly elastic steam jet, and the natural accelerations and retardations of the fluid must be accepted and arranged for in proportioning all passages in nozzles and

wheels.* If the passages of the guide curves and buckets of the hydraulic motor are smoothly curved and varied in section, it matters comparatively little precisely what method of variation of direction and section is adopted, provided, only, that the initial and final velocities of the stream are respectively a maximum and a minimum and are in parallel, respectively, with the path of the receiving and the discharging orifices on the wheel. In the case of the gas or vapor turbine, the elasticity of the fluid must be considered, and the nozzles and the wheel-passages must be carefully proportioned, to permit the natural and smooth evolution of kinetic energy and its steady absorption by the turbine disk. The enormous velocity of the fluid along the passages, and the comparative shortness of these paths within which this energy-transfer takes place, tend to make necessary, as nearly as possible, rectilinear paths across the wheel disk, with uniform retardation, and the design of the curves, on and in the wheel, which shall permit nearly rectilinear movement of the fluid in space, must, for full success, be mathematically accurate, and, in construction, perfectly reproduced by the workman or his tools, which are best automatic like the gear-cutter.

The best form of curve is that which causes least loss of energy and at the same time produces such total centrifugal action, if any, as may be best for the kind of wheel to be constructed—*i.e.*, that which gives minimum centrifugal action in outward, and maximum in inward, flow-wheels. Losses of energy due to friction and malguidance are least in paths of smallest curvature. Centrifugal action is maximum on curves of small curvature, and on those which deviate least at the terminal end; while it is zero when the path of the fluid in space is a straight line, since its magnitude is determined entirely by the path in space, not by the path on the wheel.

The curve may be laid down very readily by plotting the desired path in space on a full-size drawing of the wheel, and from it determining the path on the wheel; or it may be obtained by tabulating a series of differences of absolute and relative velocities of the fluid and of velocities of wheel, and laying down the curve, step by step, as the resultant of the

* The writer has shown how these paths are to be laid down and passages designed from the plotted curves in *Journ. Franklin Inst.*, December, 1883.

motions of the vapor and the wheel; or it may be directly plotted from its equation.

As already and long since shown by the writer, these equations are often easily derived when the conditions are specified.*

n = the ratio $\frac{r_2}{r_1}$ of the radii at the points of entrance and exit,
α = the terminal angle between the jet and tangent,
β = the angle of discharge,
u = velocity of direct flow,
w_1 = velocity of whirl of receiving side of wheel,
w_2 = velocity of whirl of discharging side of wheel,
a = angular velocity of the wheel,
r_1, r_2 = the radii.

The elementary angle, $d\gamma$, traversed on the wheel is the difference between the angles, $d\varphi$ and $d\theta$, traversed by the wheel and by the fluid. Then

$$d\gamma = d\varphi - d\theta. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The angle moved through by the wheel is always directly proportional to the time, since the rotation of the wheel is uniform, and

$$d\varphi = cdt. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The motions of the fluid, both in whirl and in direct flow, are determined by the designer. In illustration, take two common cases:

(1) Let the path of the fluid in space be rectilinear and the retardation uniform.

The equation of the path is then

$$\Delta s = (r - r_1) \text{ cosec. } \alpha, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and, since retardation is uniform,

$$\frac{d^2s}{dt^2} = -f. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Then

$$d\varphi = cdt\,;\ ds = V_1dt - ftdt, \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$r - r_1 = \text{sin. } \alpha \left(V_1 \frac{\varphi}{c} - \tfrac{1}{2} f \frac{\varphi^2}{c^2} \right), \quad . \quad . \quad . \quad . \quad (6)$$

* *Trans. A. S. M. E.*, 1883.

and, for any value of φ,

$$\varphi_m = c\sqrt{\left(\frac{(r_m - r_1)^2}{\sin.^2 \alpha} + \frac{V_1^2}{c^2 f^2}\right)} - \frac{V_1}{f}. \quad . \quad . \quad . \quad (7)$$

The values of the constants are easily determined. V_1 is the velocity of exit from the nozzle, and is obtained from the equation

$$V_1 = \frac{u_1}{\text{cosec. } \alpha}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The value of c is known when the speed of the wheel is given and f is fixed by the value of V_1, thus:

$$s_1 = \frac{V_1^2}{2f}; \; s_2 = \frac{V_2^2}{2f} = \frac{u_2^2 \text{ cosec.}^2 \beta}{2f}; \quad . \quad . \quad . \quad . \quad (9)$$

$$s - s_1 = (r_2 - r_1) \text{ cosec. } \beta = \frac{V_2^2 - V_1^2}{2f} = \frac{u_2^2 \text{ cosec.}^2 \beta - V_1^2}{2f};$$

$$f = \frac{u_2^2 \text{ cosec.}^2 \beta - V_1^2}{2(s_2 - s_1)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

making $u_2 = bu_1$,

$$f = V_1^2(b^2 \text{cosec.}^2 \alpha - 1) \div 2(s_2 - s_1) = \frac{V_1 \sin. \alpha}{2(r - r_1)}(b^2 \text{cosec.}^2 \alpha - 1) \quad (11)$$

(2) Let the direct flow be uniform and the whirl uniformly retarded as in the hydraulic turbines of Vallet.

We have, for the path *in space*, $r d\varphi = c dt$; $dr = e dt$; $dv = d.\frac{r_2 - r}{r_2 - r_1} v_1$; $r d\theta = v dt$.

When the path has been extended from r_1 to mr_1, since $\frac{r_2}{r_1} = n$,

$$\theta_m = \frac{v_1}{e(n-1) r_1} \int_{r_1}^{mr_1} (nr_1 - r) \frac{dr}{r};$$

$$= \frac{v_1}{e(n-1)} (n \log_e m - m + 1) \quad . \quad . \quad . \quad . \quad (12)$$

When $m = n$,

$$\theta n = \frac{v_1}{e(n-1)} (n \log_e n - n + 1) \quad . \quad . \quad . \quad . \quad (13)$$

The values of θ_n locate the position of the terminal of the curve.

For the path *on the wheel* and the form of bucket,

$$\varphi = \frac{w_2}{r_2} = \frac{w_1}{r_1}; \; dr = edt; \; rd\theta = vdt;$$

$$rd\varphi = \frac{w_1}{r_1} rdt; \; d\gamma = d\varphi - d\theta; \; v = \frac{r_2 - r}{r_2 - r_1} v_1;$$

$$d\gamma = \left(\frac{w_1}{r_1} - \frac{v}{r}\right) dt;$$

$$= \left(\frac{w_1}{er_1} - \frac{nr_1 - r}{e(n-1)r_1 r} v_1\right) dr \quad . \; . \quad (14)$$

$$\gamma_m = \int_{r_1}^{mr} \left(\frac{w_1}{er_1} - \frac{nr_1 - r}{e(n-1)r_1}\right) \frac{dr}{r};$$

$$= \frac{w_1}{e}(m-1) - \frac{v_1}{e(n-1)}(n \log_e m + m - 1) \; . \; . \quad (15)$$

and when $m = n$,

$$\gamma_n = \frac{w_1}{e}(n-1) - \frac{v_1}{e(n-1)}(n \log_e n + n - 1) \; . \; . \quad (16)$$

which are the equations of the line of the bucket-curve and of the path of the fluid on the wheel. Making $w_1 = o$, we have $\gamma_m = -\theta_m$.

When $w_1 = v_1$, as in uniform direct flow,

$$\gamma_m = \frac{v_1}{e}\left(m - 1 - \frac{n \log_e m}{n-1} - \frac{m-1}{n-1}\right) \; . \; . \; . \quad (17)$$

$$\gamma_n = \frac{v_1}{e}\left(n - \frac{n \log_e n}{n-1} - 2\right) \; . \; . \; . \; . \; . \quad (18)$$

Equations may be similarly derived for any practicable method of flow. It will, however, be sometimes found impracticable to adopt certain forms of bucket with certain proportions of wheel, and only careful study will determine the best arrangement.

It has been observed that the conversion of the energy of the steam into kinetic energy all occurs in the nozzle in the case of the simple turbine; and it has been seen that the work thus performed, and ultimately seen in the form of *vis viva*, is pre-

cisely that of adiabatic expansion from the same initial to the same terminal pressure behind a piston. The forms of the curves of velocity and pressure have been given by Mr. Hodgkinson for a well-designed jet, and are here reproduced, with the sketch of the nozzle (Fig. 84):

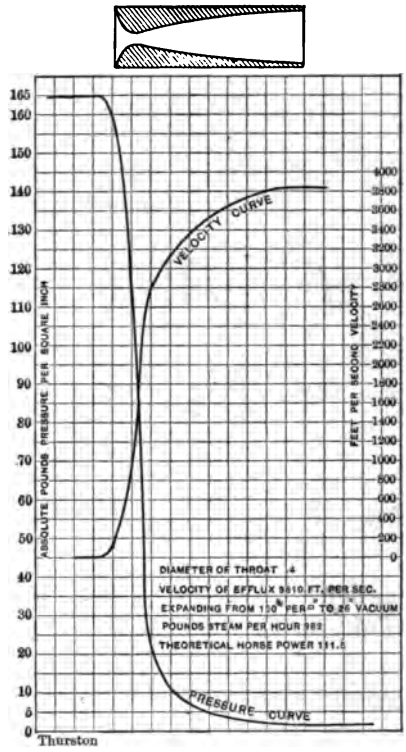
ABSOLUTE POUNDS PRESSURE PER SQUARE INCH
FEET PER SECOND VELOCITY
VELOCITY CURVE
PRESSURE CURVE
DIAMETER OF THROAT .4
VELOCITY OF EFFLUX 3810 FT. PER SEC.
EXPANDING FROM 150 PER ☐" TO 26 VACUUM
POUNDS STEAM PER HOUR 382
THEORETICAL HORSE POWER 131.5
Thurston

FIG. 84.—PRESSURE AND VELOCITY CURVES.

DISCUSSION.

Mr. Harrington Emerson.—The reciprocating steam engine has very nearly reached its limit of excellence in several respects.

I.—WEIGHTS.

The lightest practical marine reciprocating engines ever built are the triple-expansion engines of the torpedo-boat "Dahlgren," which weighed 42 pounds per indicated horse-power in 2,100 horse-power units. This machinery was enormously expensive, made of special material, all pins drilled to lessen weights, etc.,

etc. The speed attained by the "Dahlgren," a 151-foot boat, was 30.5 knots. The consumption of coal was not small. The best record for boats of this class is 2.5 pounds per indicated horse-power.

These "Dahlgren" weights are wholly abnormal. A tabulation of weights of engine and boiler-room equipment of nine steamers shows, in the mercantile service, weights running from 329 pounds to 510 pounds, and in the navy 165 to 194 pounds per indicated horse-power. The machinery of a large recent steamer of 3,400 indicated horse-power weighs, steam up, 356 pounds per horse-power. On the modern ocean liners the weight of machinery is between 300 and 400 pounds per indicated horse-power. In an ocean liner of 26,000 horse-power, 323 pounds is the weight per indicated horse-power.

The "Turbinia," 100 feet long, driven by a Parsons steam turbine, made 34.5 knots in an hour's run.

The marine Parsons steam turbine, including the boiler, shafting, propellers, and all other appurtenances, weighs 30 pounds per indicated horse-power on a coal consumption of less than 2 pounds.

It is therefore evident that, weight for power, the Parsons engine surpasses any reciprocating engine ever made, weighing but one-tenth to one-seventeenth mercantile practice, and about one-sixth naval practice.

II.—Efficiency.

The most efficient marine engine ever used is the quadruple-expansion engine of the steamship "Inchmona," a steamer 348 feet long, which, during a nine months' cruise, consumed only 1.15 pounds of coal per indicated horse-power, probably about 10.5 pounds steam per brake horse-power.

The best Atlantic liners burn 1.5 pounds coal per indicated horse-power.

It is impossible to make accurate comparison between a report as to coal used and one as to steam used, as the former involves the boiler efficiency, but direct comparison can be made between the record of the Parsons steam turbine and the very highest records of triple or quadruple-expansion stationary pumping and marine engines.

Up to 1893 the highest economy on record was the triple-ex-

pansion Milwaukee pumping engine, 574 horse-power, 10 pounds of steam per indicated horse-power. The highest record for a compound engine is that of the Louisville pumping engines, 12.25 pounds steam per indicated horse-power. The data of other record-breaking engines are:

	Horse-power.	Pounds steam per I. H. P.
Best locomotives	....	24
Willans compound	....	14.7
Worthington pumping engine	260	14.1
Willans triple	....	13.02
Sulzer	615	11.85
Allis pumping	574	11.68
In Marine Compound Engines.		
"Ville de Douvres" (paddle)	2,977	20.8
"Tusiyama"	....	21.2
"Colchester"	....	21.7
Triple Expansion Marine.		
"Tartar"	....	19.8
"Meteor"	1,994	15
"Iona"	645	13.35
Parsons's "Turbinia" (100-foot boat)	....	13.75
One of the most economical marine engines afloat	1,440	11
Steamship "Inchmona," quadruple	....	10.5
Westinghouse-Parsons steam turbine, equivalent indicated 400 horse-power	....	10

"Taking the most favorable results which can be regarded as not exceptional, it appears that in test trials with constant and full load the expenditure of coal and steam is about as follows:

	Pounds per I. H. P.	Pounds per Ef. H. P.	
Coal	1.50	1.75	
Steam	13.50	15.80	17 per cent. more.

These may be regarded as minimum values rarely surpassed by the most efficient machinery, only reached with very good machinery in the favorable conditions of a test trial." (Kent, pp. 785 and 786.)

Small engines are notorious fuel-consumers and steam-eaters. In the United States navy the steam auxiliaries use an average of 119 pounds steam per indicated horse-power. There is no hope of getting them below 80. The Parsons steam turbine in the little "Turbinia" used 13.75 pounds of steam per indicated horse-power, almost equalling the best marine triple-expansion

engine of which I have a definite record, that of the steamship "Iona," 13.35.

It may therefore be said that under the doubly unfavorable conditions of torpedo-boat limitations and of being the first experimental marine engine of its kind ever built, the Parsons steam turbine not only equalled the best record of triple-expansion marine engines, but also broke the speed record for any steamboat of any size or description.

The American Parsons.

At Pittsburg I examined the first American-built Parsons turbine. It was direct-connected, with a 300 kilowatts generator. It gave a kilowatt or 1.34 horse-power on the switchboard for an uncorrected steam consumption of 16.4 pounds. In efficiency horse-power this is equal to 12.24 pounds. Allowing a dynamo efficiency of 93 per cent. (which is very high), we obtain about 11.38 pounds of steam for the turbine alone. This is effective. An allowance of 15 per cent. less can properly be made for comparative indicated horse-power, bringing the comparative consumption down to 10 pounds. This small single experimental turbine therefore beats the record of the four times as large quadruple-expansion engines of the "Inchmona."

It is fairer, however, to compare the turbo-generator with reciprocating steam-engine generating sets.

A compound Willans, with an Edison-Hopkinson dynamo, on careful test, showed a steam consumption of 33.33 pounds per kilowatt. The steam generating set on the United States steamship "Wisconsin" used 32 pounds per kilowatt on 12-hour test, both about double the consumption of the first American built Parsons turbine.

"The remarkable economy of the turbine is due to two main causes:

"Whereas in reciprocating steam engines the ratio of expansion is between 9 and 16-fold, in the turbine it is between 100 and 200-fold.

"Whereas in the reciprocating engine there are innumerable tight-fitting joints causing internal friction, in the turbine the internal friction is almost eliminated."

Leaving out boiler-room weights and considering only engine weights, the Parsons turbine weighs but one-tenth as much as naval engines, one-twentieth as much as mercantile marine

engines, and shows a fuel economy of 20 to 25 per cent. for the same power.

The Parsons Turbine as a Marine Engine.

The drawbacks to the Parsons turbine for marine use are many. Its speed of revolution is very high—at Pittsburg, 3,600 revolutions per minute. At lower speeds it is not efficient. This high speed, admirably adapted to dynamos, requires special designs of propellers. To put the matter briefly, instead of one or two large propellers, 9 to 16 small ones are used; instead of one or two turbines, there are 8 or 12 used. It is impossible to reverse, except in a separate reversing turbine; it is very wasteful to run at any speed except at the highest. Just as the tremendous energy of powder will drive a small projectile at high speed, but not drive a big ship at all, so the Parsons turbine will drive a little boat very fast, but will not drive a big vessel slowly. The engine velocities are too high. Therefore the "Turbinia" runs 40 miles an hour—not because it is desirable, but because it must—and the little 100-foot boat is burdened with 2,100 horse-power engines.

The Parsons Adapted to Electric Boats.

The Parsons turbine is particularly well suited for electric generation. Here high speeds are valuable, lessening the weight of dynamos.

This suggests the use of the Parsons for the generation of electricity to be used in driving a motor.

If we should take the Pittsburg Parsons turbo-generator and put it in a ship, we could install it in a 250-foot vessel of 800 tons displacement. We should ask the naval engineer to design one or two propellers to drive such a ship at a 10-knot rate. The required propeller revolutions being known, we should ask the electrical engineer to design a motor of maximum efficiency for that speed. We should trim the ship with a storage battery. Good generous weights would be:

Steam turbine, per indicated horse-power.....		15	pounds.
Boiler room	" "	30	"
Generator	" "	40	"
Motor	" "	50	"
Accumulator	" "	200	"
		335	"

The accumulator is a variable quantity. All the other machinery weighs less than naval practice. With accumulator, the weights are below those of mercantile practice. With engine running, the accumulator equalizes output and consumption, as in trolley and light installations. As marine engines run steadily, fluctuations, or peak roads, are not excessive, and therefore a large accumulator is not necessary. Also, a comparatively small reduction in speed reduces greatly the power required for propulsion. If the normal speed of a large boat, 250 feet, is 10 knots an hour, one-half the power will drive it at 8 knots, one-quarter at 6 knots, and one-fifteenth at 4 knots. This latter speed is quite sufficient to move around a harbor—to and from a dock, or to maintain headway—with engines not running.

A battery to drive the steamer 5 hours would weigh about 60 pounds per horse-power of the engine. A battery of 240 pounds would drive the boat 5 hours at 6 knots, 18 hours at 4 knots—make it answer the helm for several days if the machinery were disabled.

The turbine required would use but little over a pound of coal per indicated horse-power, or 12.24 pounds water per brake horse-power on switchboard. This is about 1.25 pounds of coal per indicated horse-power. In passing the current through the motor there may be a loss of 10 per cent., which will increase coal consumption to 1.4 pounds.

The average of twenty-eight crack steamers of the highest class is 1.52 pounds of coal.

But a fraction of the current passes through the accumulator. It is therefore possible to use the combination of steam turbine and electricity as economically as with best reciprocating engines.

Where is, then, the Advantage?

In the marine engine I have considered only the main engine. On every big ship there are a number of auxiliaries. There are steam pumps, steam fans, steam steering-gear, steam winches, steam electric plants. On some of the large cruisers these auxiliaries consume 40 per cent. of the coal. One of the most economical vessels afloat, 6,800 tons dead weight capacity, with 19 tons of coal runs 9 knots. In one of the United States battleships the auxiliaries alone used 17 tons daily. It has been found possible to drive a cruiser 6 knots an hour by using

merely the exhaust steam from the auxiliaries. Each little engine may be fully as much trouble as the main engine, and on many steamers a special engineer is employed to look after them. They are always breaking down. These little engines consume from 80 to 300 pounds of steam per indicated horse-power. Even now they are being replaced by a number of electric sets, by which it is hoped to reduce steam consumption to 40 pounds. With an accumulator the steam used should not exceed 20 pounds. All these steam auxiliaries fall away in the turbo-electric combination.

All the auxiliaries are run from the storage battery. While lying at dock there is no need to keep up steam. The vessel can be instantly lighted, anchor weighed, a change of berth made, without calling on boiler room. Whereas the actual coal consumption in the navy reaches $2\frac{1}{2}$ pounds, it ought not to exceed $1\frac{3}{4}$ pounds in the combination boat.

Simplicity.

A second great gain is in simplicity. The turbine is the simplest of engines, little more than one revolving part. Even the governing arrangement is simplicity itself. For no load a short puff of steam is admitted, followed by a pause. As load increases, puffs lengthen, pauses shorten, until at full load the admission of steam is continuous. The losses between indicated and effective horse-power are very much diminished. There are fewer bearings to oil, fewer repairs, fewer opportunities of damaging machinery. This lessens the wage charge, and on a steamer of the size considered, wages equal coal bill. Owing to the smaller amount of coal used there are fewer firemen, stokers, and coal passers. In the engine room oilers and wipers are dispensed with, as there is nothing to oil or wipe. An electrician takes the place of one of the assistant engineers.

Repairs of turbo-generators, seldom necessary, are remarkably low in cost, as has been demonstrated by the actual behavior of steam turbines in use for ten years. The durability is also great, there being one instance of a turbine driving a fan having run continuously day and night for three years.

There is absolute gain in weight.

There is gain in space. The turbine lies low along the keel. The batteries also lie along the keel and help trim the ship.

The saving in boiler room is counted at 20 per cent. by Mr. Parsons.

Mr. Parsons's own summing up of the advantages, even with his multiple propeller, multiple turbines, and shafting are:

Less space.
Weighs one-half.
No vibration.
Fewer employees.
Less oil and stores.
Small head-room.
No noise.

The combination proposed would cost more than the usual fair-to-good marine engines, but it would not cost as much as the special freak engines of torpedo-boat practice.

Mr. Westinghouse has acquired the right to the Parsons for land purposes only. This was definitely explained to me at Pittsburg, and confirmed to me by a letter from Mr. Parsons in England, who has reserved the rights to use his turbine for the *direct propulsion of boats.*

The facts in this report have been gathered from a correspondence of several months with Mr. Parsons, who has sent me a number of documents; from personal interviews at Pittsburg with the designers of the American Parsons turbine, with whom I had a full discussion of its capabilities; also from discussion and consultations with four or five of the Westinghouse expert electricians as to a turbo-electric installation; also with the experts of the Storage Battery Company at Philadelphia, as to the possibility of combining a generating set, a motor, and a storage battery in a boat of large or small size.

Mr. Charles E. Sargent.—One advantage which the turbine has over the reciprocating engine which I believe has not been mentioned in summing up these advantages is—on account of the ability to run the former without admitting oil with the steam (as there is no rubbing contact)—not only a saving in oil, but the redistillation of the condensed steam, when the same is used for making ice in refrigeration plants using the ordinary reciprocating engine, is obviated.

I think the disadvantages of our present steam turbines will vanish as inventors begin to realize the importance and desirability of supplanting the modern comparatively slow-going reciprocating steam engine with the ideal steam motor.

Mr. William Kent.—I would like to ask Dr. Thurston if he can inform us what is the source of the loss in the turbine by reason of which, while the turbine is the engine of maximum thermal efficiency, yet it has higher steam consumption than the reciprocating engine. In the table on page 215 I find for the de Laval turbine the lowest figure at 200 horse-power is about $16\frac{1}{4}$ pounds of steam per horse-power per hour. As for effective horse-power, I suppose that about equivalent to 14 pounds of steam per indicated horse-power per hour. On another page, the lowest figure for the Westinghouse engine is 16.4 per electric horse-power, which, would be between 14 and 15 pounds per indicated horse-power. What is the reason that the turbine under its best efforts shows such a consumption of steam as against from 11 to 12 pounds shown in the triple-expansion engine?

Mr. Engel.—I should like to ask Professor Thurston, as he has given us all the information on the subject, to explain to us the means which have been adopted to reverse this engine for marine purposes. Of course in marine practice it is necessary that the boat should back with about the same power that she can go ahead, in case a collision is liable to occur. I understand that this turbine will not reverse, and that it has been necessary to put in a special engine to do the backing. Of course this engine which is put in to do the backing is smaller than the engine which drives the boat ahead. Consequently if a collision is imminent, it is not possible to stop the vessel, except in a very long distance, perhaps too late to avoid the danger. I would like Professor Thurston to enlighten us on that subject, if he will.

Mr. Reginald Pelham Bolton.—It is perfectly evident from the diagram issued with this paper (Fig. 71), that the economy has suffered very considerably from variation in load, as well as in speed. It would almost appear that the application to marine practice was about the most undesirable form in which the engine could be utilized. It appears to me, and no doubt to many others, that the proper application of this engine on board ship would be to drive a generator at a constant speed, the screw shafts being operated by motors, which would be practically uniform in their economy at varying speeds, and perfectly capable of reversal. That has so far not been done, although it has been talked about, and although it seems a kind of foolish

idea first to generate current and then to distribute it, when the distance between generator and motor is so small, there are reasons, which I think are apparent on the face, why that may be the combination which will probably lead up to practical results in the future. In any case it would get over the difficulties which the previous speaker has referred to in regard to reversing screws, which, at the present moment, is the greatest difficulty in the application of the turbine to marine practice, not to speak of the other difficulty of subdividing the screw into so many blades, and driving them at so very high a rate of speed as to cause a cavity in the water, which difficulty is referred to in the paper.

Mr. John Platt.—I would like to say, in reply to Mr. Bolton, with regard to marine work, that with very high speeds the question of weight comes into play to such a very considerable extent that to drive electrically with a turbine and then transmit to the screw would bring in such a very great excess of weight as to make it impracticable. What he says may be true, but the fact still remains that the Parsons turbine has only been fitted to three boats, and in those three the inventor has been able to obtain a speed with a legitimate navy boat—a destroyer—of 36 or 37 knots, very much in excess of anything that has been done with a reciprocating engine. A destroyer of about the same displacement has been made to run at $32\frac{1}{4}$ knots for three hours with a reciprocating engine. It has taken 20 or 30 years to work up their speed with the standard marine engine, and with the turbine I think they have been about 5 years developing the boat, and have been able really to get, under regular navy trials in England, 36 knots. I think this is really a very remarkable performance.

For electric light work and constant driving, Dr. Thurston points out that the turbine is a very simple machine. This being the case, it is very much of a surprise to me that so little has been done with it in the last 12 or 14 years. In 1888 I was in Watson's Works, in England, and Mr. Parsons was showing me the turbine running there. They have been working at it since, but it does not seem to me that they have done as much work in the electrical branch as one would have expected.

Mr. George I. Rockwood.—I have followed the development of the Parsons turbine with great interest, and I cannot help believing that little but conservatism and commercialism—vested

interests, that is—stand in the way of its adoption in steamships, whether for naval or for merchant service. I understand that at present the price of the steam turbine in this country is almost prohibitive of its adoption in place of reciprocating engines. Whether that has got to be so to the end of time is another question; but at present the builders ask a very high price for it per unit of power. That is one thing which stands in the way of adopting it. I understand also that there is some practical difficulty in the way of close-speed regulation. This, however, does not affect its usefulness in marine plants.

Dr. Thurston emphasizes in the paper that all turbines are necessarily uneconomical, except at one particular point in the gate opening, and he urges this feature of the steam turbine as one calculated to hinder its adoption in ships in the place of the reciprocating engine. As for the water turbine, it is to-day more economical over a wide range of load, as compared with the point of best economy, than the reciprocating steam engine is. I understand that the inventor of the steam turbine—the Hon. Charles Parsons—claims that the same thing is true of the steam turbine; that the steam turbine is not such a great waster of steam at light loads.

Mr. Emerson.—Not at light loads, but at variation of speed. You must run at constant speed, but you can vary your load as much as you see fit.

Mr. Wheeler.—That applies to steam engines as well.

Mr. Emerson.—In the marine turbine there is the particular difficulty that you cannot run slow. This "Turbinia" has to run at 30 miles an hour, because it cannot run slower.

Mr. Rockwood.—That was, I believe, the very proposition that Mr. Parsons denied. If I remember correctly, it was stated editorially in *The Engineer*, and denied almost seriatim by Mr. Parsons. I know nothing about it myself. I only have the inventor's word for it. But the turbine is a very small machine, compared with the engines of equal power of a battleship, and I am willing to believe that Mr. Parsons is right in claiming that a ship may have a sufficient number of propellers and turbines, and may have these so disposed, as to actually give a better average economy than if provided with reciprocating engines. And how can a man choose the latter for a torpedo boat if he can get a turbine?

A Member.—You can't get a turbine.

Mr. Rockwood.—Then that point ought to be brought out and not the economical difficulty about the turbine.

The Member.—We have been trying for two years to get one.

Mr. Rockwood.—I believe that is the real difficulty about the use of the turbine in ships. They are superior to the ordinary reciprocating engine for high speeds.

Mr. Arthur Herschmann.—To my mind one of the greatest difficulties in the way of the universal application of the steam turbine is really the gearing. In the average case it would be necessary to gear it down once or twice. Granted, in other words, that the turbine would be superior to the reciprocating or high-speed engine, that superiority would be counterbalanced by the waste in friction on account of one or two gears. I do not think it is out of the way if I mention that a friend of mine, Engineer Lenz (who became quite prominent in the Paris Exposition for a thousand horse-power drop-valve engine which got a gold medal), and myself designed some years ago a kind of clutch or speed-gearing device, which was then considered rather promising, and which Messrs. Greenwood & Batley, of Leeds, England, commenced to manufacture. Although it is now more than three years ago they do not seem to have done much with it. The idea was to introduce a clutch which can be coupled up to one side of the motor and transmit power to the other side, regardless of the speed of the motor. While, therefore, one side of the clutch could be run at any speed, the other side could be run from zero to maximum just at the will of the operator. The clutch consisted of a large casing which was filled with heavy oil, and this casing was attached to the engine or turbine or any motor that was intended to be run at constant speed. Within this casing we had propeller blades or knife edges, solid with the "driven" shaft. Of course, it is easy to imagine that if these blades were twisted (which was done at the will of the operator) so that they would cut through the liquid the clutch would not transmit power. Once they were twisted so as to present resistance, they would impart friction and force the liquid through pockets cast in the driven side of the clutch, and accordingly, while it was possible to run the motor on one side at constant speed, we were able to change the speed on the other side from zero to maximum. Messrs. Greenwood & Batley had then made a couple of these clutches, and they considered them promising. One, I think, was for 50 horse-

power. I suppose it will be clear how this clutch operated. We looked up all the records at that time, and found that in marine work a similar principle, some 20 or 30 years ago, had been utilized, though not for the same purpose; to check the racing of the engines when the screw rises out of the water. It was a marine governor. Our plan was to dispense with gears and yet to be able to run one side of the clutch at a constant speed and to operate the other side at variable speed. We were actually able to do this in the small sizes, and the device promised to become a success; but it can readily be imagined that in large sizes the waste of friction would become very great, and the chief difficulty was that at high speed the oil would be so heated that it became too fluid to cause any frictional resistance on the blades and pockets. In fact, the blades would then simply cut through the oil, without moving it.

The speaker thinks that if this device were successfully developed it would prove very valuable in connection with the driving of cutting tools, inasmuch as certain high-speed motors of small sizes, electric or others, could be more conveniently used for the purpose.

Mr. Henry I. Snell.—Referring to that part of this discussion in which reference has been made to the cost of manufacturing these reaction or turbine engines, I recall a conversation I had some years ago with Mr. William Baxter, the designer of what is known as the Baxter engine.

I asked him why he did not apply his great inventive talents and mechanical abilities in producing a successful and practical rotary engine which would fill "a long felt want," something which would give a high rotary speed, as such a machine was a desirability in many instances, and the field was ripe for it.

This was before the day of electric motors. He replied very promptly and decisively that the problem was one of very simple solution; all you had to do was to take two circular plates, similar to circular saws, cut semi-circular grooves spirally radiating from the centre to the periphery, fasten these plates together so the grooves of one would cover the grooves of the other, thus making a circular hole from the centre to circumference of a nicely balanced plate, then place this united plate, securely fastened upon a hollow shaft or arbor, supply the journal boxes and the necessary stuffing-box attachment to the

steam pipe from a boiler, and let the steam pass through the shaft and out at the periphery of the circular plate.

If you make the curves through the plates of the proper form, probably an arithmetical spiral, so the escape of the steam from the plate will not be at a velocity much greater than the velocity of the periphery of the wheel, you will have absorbed all or nearly all the energy in the steam which has been transformed into work, and as very little of this energy will be required in the friction of the engine itself, you have an economical and durable rotary engine at small first cost.

Mr. Platt.—The last speaker but one was evidently referring simply to turbines for stationary work, and not to marine turbines, in the remarks that he just made. I believe I am correct in that statement. I refer to what he says in regard to the Westinghouse Company.

Mr. Emerson.—Yes, that was stationary work, of course. They were not marine turbines. They have nothing to do with the marine end of it.

Mr. Platt.—Mr. Rockwood referred to the question of 30 knots, and of it's being necessary to run at that speed to attain any degree of economy. As a matter of fact the practice is, and will be, to use three shafts; then you can use either one, two, or three at full power, and get full economy out of practically all three combinations.

Mr. Wheeler.—How about the reversal? I have forgotten the record. I refer to the torpedo-boat destroyers.

Mr. Platt.—They do not give any information on the subject.

Mr. Wheeler.—I thought perhaps you might.

Mr. Platt.—No.

Dr. Thurston.—Regarding the first question by Mr. Kent, respecting discrepancy between the ideal, computed economical performance of such an engine, and the real performance:—I suppose the discrepancy arises from the class of defects which are observed in the ordinary form of engine—defects in design, defects in construction, and defects in operation. There are certain principles that must be adhered to if the design is to be correctly made. That design must be perfectly carried out in construction, or the results anticipated cannot be secured; this means corresponding perfection of methods of construction and of workmanship. Finally, the machine, if properly designed and properly constructed, must be worked in a proper manner. I

presume if we could get at this engine to analyze it, we would find that while the total amount of waste is practically the same in this and the older class of engine, it occurs in somewhat different ways, though from the same general class of causes. I imagine in the steam turbine we will find, for example, that leakage and the friction of liquids, where the steam is wet, take the place in waste of that large percentage of loss of effect observed in the other forms of engine, as waste due to cylinder condensation. But there may here be defects in the form of the nozzle, defect in failure to secure complete conversion of available energy into kinetic energy, actual *vis viva*, of the flowing steam. There may be defects in design and, later, in construction, in the forms of the passages and in methods of construction of passages, in forms, proportions, and paths for the jet, because of which the amount of energy so obtainable is not fully converted from the one form into the other. There will always be leakage where there is a pressure on the one side of the turbine and lesser pressure on the other. I presume these various defects will gradually become identified, their quantities will be measured, and the engineer will then give his attention to the correction of them, in the order of their importance, precisely as has been done during the history of the ordinary steam engine during this century. I have no doubt that when the steam turbine has had as long a period of development and evolution as has had the common engine of to-day, it will have acquired quite as high perfection as has the engine of to-day.

Regarding reversal:—As the turbine is now usually constructed, reversals cannot occur in the turbine itself. It either must be connected with a reversing mechanism, like a reversing clutch, or it must be thrown out of use and the reversal effected by another turbine, as has been actually done by Mr. Parsons. I see no difficulty, however, in making a turbine which can be reversed as promptly and effectively as a locomotive engine, or more so, and I have no doubt that the ingenuity of our inventors will find a way of accomplishing this. There have now been about 250 patents issued from our Patent Office, and, as time goes on, more will be added. Among these various coming inventions, some will be directed to this point, I have no doubt, and we may reasonably hope to see, ere long, a turbine which, where it is desired, can be made to reverse without special difficulty and without important loss of efficiency.

Regarding change of load with varying speed:—It is true of the normal hydraulic turbine that it must have a fixed normal speed, and the loss of efficiency, with variation from that speed, will always be something considerable. It is possible in the design of a hydraulic turbine, and I presume of these steam turbines, to make the range of variation of efficiency less with a given variation of speed by a proper design; but it is not possible to entirely evade it, nor is it, I think, quite correct to say that the hydraulic turbine, even at constant speed, can be made to give the same efficiency with varying loads. With the exception of one form, the "partial turbine," the turbines built and used throughout the United States will always be found, I imagine, on test, to show variation of efficiency with varying loads, from full gate to any less gate, and it will have some such form as that [making a curve upon the blackboard]. And in a few cases, as with a turbine built at Holyoke, we may sometimes find the maximum at $\frac{3}{4}$ gate; but that means that the turbine is fitted to run with the amount of water flowing designated at that point, and thus does its best work at that point. The Hercules turbine was the first, I think, to secure anything like a satisfactory curve. But in the very best turbines I have ever seen, that one included, we do get varying efficiency with variation of load, and with variations of load and speed which characterize the conditions of ordinary work, we may get wide variations of efficiency. Mr. Parsons has been said to have denied that the steam turbine thus behaves. I do not think Mr. Parsons did deny precisely that; what he actually said, so far as I know—Mr. Rockwood may refer to something else—was in a letter to London *Engineering*, giving a set of data showing that, with varying loads *in electric light plants*, he was able to get a variation in efficiency which was comparatively small.

But that is a case in which we have a constant speed. We have no proof that, with varying load and speed, any one has evaded this, which seems to me to be an inherent law of turbine action.

Regarding the use of expedients for evading this difficulty, as, for example, the introduction of an electric generator and motor, I think that, as has already been stated, it will be found that when it is considered what enormous costs, what great weights, are involved in the introduction of a complete set—generator and motor, and auxiliary mechanism with the steam turbine—it will be seen that costs, complications, and defective effici-

encies will make it probably preferable to use the common form of engine. I doubt very much, assuming the practicability of installing such a plant without excess of weight over the common type of steam engine, if it will be found to be a practical improvement to substitute that scheme for the ordinary construction of the marine engine. A paper by Professor Durand, published in *Marine Engineering*, throws some light upon the subject. He there studies the conditions of operation of the torpedo boat of the class of the "Turbinia," and shows that in order to substitute either for the reciprocating engine or the steam turbine, as there constructed, such a system of electric generation and utilization, it will be necessary to use several other boats to carry the machinery.

Mr. Emerson.—Was not that with reference to a torpedo boat with storage batteries?

Dr. Thurston.—Yes, it was. That modified the question to some extent.

Mr. Emerson.—Professor Durand sent me that paper, and I had some correspondence with him on the subject.

Dr. Thurston.—Yes, you are right. The system includes storage batteries.

Regarding the cost of building referred to by Professor Carpenter:—There is no question but that it is a comparatively expensive machine to build to-day. I see no reason, however, as another speaker has also remarked, why we may not fairly expect, once the machine comes into general use, to be able to build it with all the accuracy of the finest machinery of to-day in any department, and yet at moderate cost. The illustration of the bicycle is exactly to the point. I see no reason at all why this extremely fine workmanship, which is imperative if we are not to have serious leakage, may not be obtained by a system of construction that shall involve the building to exact gauge largely by automatic machinery and with careful inspection, so that the machine when completed shall become not only the simplest of steam engines, but possibly the most economical of steam engines, and also the most perfect construction of steam engine that up to that time the world shall have seen.

Since the meeting* I have now had the opportunity to read

* Author's closure, under the Rules.

with care the comments of Mr. Emerson on the turbine for marine work, and am glad to see so much new information and data regarding the Parsons machine. The contrast between the weights of the older and the newer motors is very striking, and it is to be hoped that a finally standardized practice, born of experience with the steam turbine in its various forms, will fully sustain the advantage which it now apparently exhibits in this respect.

It should be remembered that there may be as many forms of gas and vapor as of the hydraulic turbines, and many bright minds are already working, not only on the forms suitable for every desirable application of the steam turbine, but also in the endeavor to secure the combined advantages of gas and petroleum or other vapor as working fluid with those of this revolutionary type of heat engine. One of the most recent and interesting investigations made at Sibley College has been a study, theoretical and experimental, of the gas turbine actuated by the products of combustion of gas or of petroleum vapor. The outcome was not altogether encouraging, but it is not yet to be assumed that we may not ultimately discover ways of utilizing these working fluids as well in the turbine as in the common form of engine. Again, various forms of turbine will be adapted, no doubt, to various sorts of work, as has already been so extensively done, particularly in Europe, with the hydraulic machine, and I see no reason to doubt that the "partial" turbine and other forms of special construction of wheel, the new and satisfactory systems of regulation and of reversal, and, in fact, any now missing, yet needed, improvement, may soon be brought into use.

I think it possible that some of the figures presented here may be subject to revision. The Milwaukee engine gave, on our trials, the figure 11.68, not 10 pounds per indicated horsepower. We need more data regarding the best work attainable with the turbine, corroboration of the already reported minima, and for various pressures, giving us thus the law of variation of efficiency in use with that variation. This will also enable us to determine the extent to which economy is gained by, and is due to, the thermodynamic change of temperature and pressure. We shall all be glad to secure evidence that the minimum figures reported at any pressure for the turbine can be safely counted upon in projected constructions, but it seems quite safe

to say that the two types of motor are fairly comparable in this respect, where of equal powers and of equally good construction. For marine work, and especially where, as in torpedo-boat construction, the requirements of enormously varying speeds, and of powers varying in vastly greater proportion still, are imperative, I think that a special form of turbine will ultimately be adopted. There should be no difficulty in securing compliance with all essential conditions.

The introduction of the storage battery at present, with its enormous weights and costs, can hardly be looked upon with satisfaction, even for short-route service. For long routes, and even for the torpedo boat, I think, it is not likely ever to prove a satisfactory system. The estimates given seem to me optimistic. A conservative judgment will, I think, accord quite sufficient advantage to the ancient type to justify its introduction for many places and purposes. With its economy established, everything else demanded will, in time, be secured. The way has been shown long since by our designers of hydraulic motors, and, in this particular field, by European builders.

Since the meeting, I have again read the paper of Mr. Hodgkinson on the work of the Westinghouse Company, illustrating the fact that an imported device may always be expected to promptly show the genius of the Yankee designer in its adaptation to its new habitat. The double-motion governor, its neat devices for packing, its nicely adjustable speed within the narrow limits needed for the alternator, and many other interesting details of construction, make it a most interesting machine from every point of view.

The writer of that paper mentions one important advantage of the turbine to which I have, perhaps, given too little attention: The limit of profitable expansion in the common form of engine, whatever its construction, is found at a pressure exceeding the back pressure by an amount measuring the sum of that pressure required to overcome friction of engine, that which limits waste by leakage and "cylinder condensation" to an allowable quantity, and that which limits cost, in the manner often pointed out and now familiar to all. This terminal-pressure limit to profittable expansion is reduced in the turbine by minimized friction, by freedom from the phenomenon known to engineers as cylinder condensation, and by reduced storage of capital. The turbine may thus profitably expand its steam far beyond the

limit set for the reciprocating engine, and, to this degree, may more closely approximate the ideal. The Westinghouse machine is reported to give unprecedented economy at light loads, but, of course, only at a constant and correct speed. There seems no doubt at all, now, that 14 to 16 pounds of slightly superheated steam per electrical horse-power hour may be fairly expected with large turbines, with condensers, if a good vacuum can be maintained without sensible excess of costs. Thus far, the special field of the machine seems to be in electrical engineering, but I disagree absolutely with the many voices declaring that the machine is "inherently incapable of reversal" or speed variation. With the coming systems of reversal, of close regulation, and of adaptation to varying loads and speeds—the former of which improvements is, I think, accomplished, and the latter most probable in the near future—there seems no limit to its field of work. The larger its scale of construction, also, the nearer does its practicable construction, even now, approximate satisfactory conditions.

The best work, so far as reported, I think, from European practice—although this, in fact, is a Parsons construction, set up at Eberfeld—is detailed in the *Zeitschrift des Vereines deutscher Ingenieure*, June 30, July 7, 1900, and reproduced in the *Revue de Mécanique*, November 30, 1900, in the report of the Messrs. Lindley, Schröter, and Weber.

No. 877.*

TESTS OF CENTRIFUGAL PUMPS.

BY W. B. GREGORY, NEW ORLEANS, LA.
(Junior Member of the Society.)

A DESCRIPTION will be given of the tests of two centrifugal pumps.

Besides making the regular efficiency test, an attempt was made to measure the loss of head due to friction within the pump. The general scheme was as follows: Suction and discharge were tapped near the pump and pet cocks inserted; by means of mercury manometers, connected by rubber tubes to pet cocks, the pressure, positive or negative, existing at those points, could be definitely known at any time. High pressures can be read by means of carefully calibrated pressure-gauges.

The total head which a centrifugal pump will produce at a given speed of rotation is a function of its peripheral velocity.

Let V_p = Peripheral velocity.
H_t = Total head.
H_v = Velocity head.
H_f = Friction head.
H_m = Static head shown by manometers.

Then

$$V_p = \varphi \sqrt{2g\ H_t}.$$

The theoretical velocity corresponding to the head H_t is

$$V = \sqrt{2gH_t},$$

and

$$\varphi = \frac{V_p}{V}.$$

In case the discharge valve be closed, H_t will be static pressure, and, knowing V_p and H_t, φ is known.

In case water is allowed to run through the pump, by open-

* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

ing the discharge valve partially or fully, a part of the head produced becomes velocity head H_v, and as soon as water flows there is a loss of head due to friction within the pump. In this case

$$V_p = \varphi \sqrt{2g\,(H_m + H_v + H_f)}.$$

If the diameter of the impeller and revolutions per minute be known, V_p can be known. φ may be obtained as shown above; and if the quantity of water be measured, and readings taken at manometers on the suction and discharge and corrected for difference of level, the only unknown in the above equation is

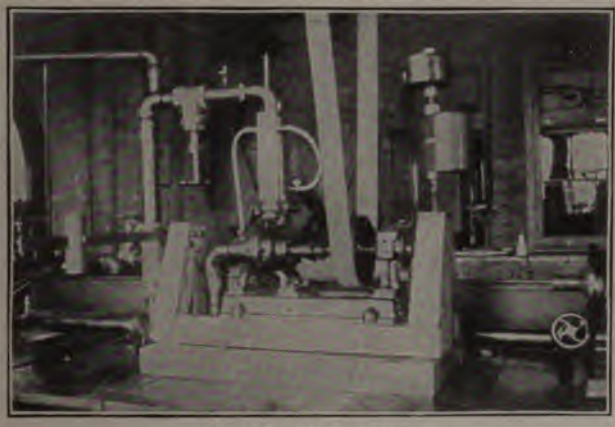

FIG. 85.—SMALL PUMP.

$H_f = H_t - (H_m + H_v)$; φ will vary with different forms of impellers or shapes of blades.

Let V_1 = velocity of water in suction and discharge at points where manometers are attached.

$$H_v = \frac{V_1^2}{2g}, \text{ and } H_f = \zeta \frac{V_1^2}{2g}.$$

That is, the loss of head due to friction in pump is a constant times the velocity head.

The efficiency of a centrifugal pump will vary greatly with the way in which it is piped. If manometers are used on suction and discharge near the pump, the sum of their readings will be the static head pumped against, plus the friction head of suction and discharge pipes. To compare two pumps of the same size, they should be piped exactly alike, or they might be given credit for static pressures produced in suction and dis-

charge near pump, which would be equivalent to eliminating suction and discharge losses and giving efficiency of pump only, instead of pump and piping, which will vary with arrangement of pipes. This is merely a suggestion. In the following tests, efficiency was computed on the quantity of water pumped and static head as measured, either by difference of level or, in case

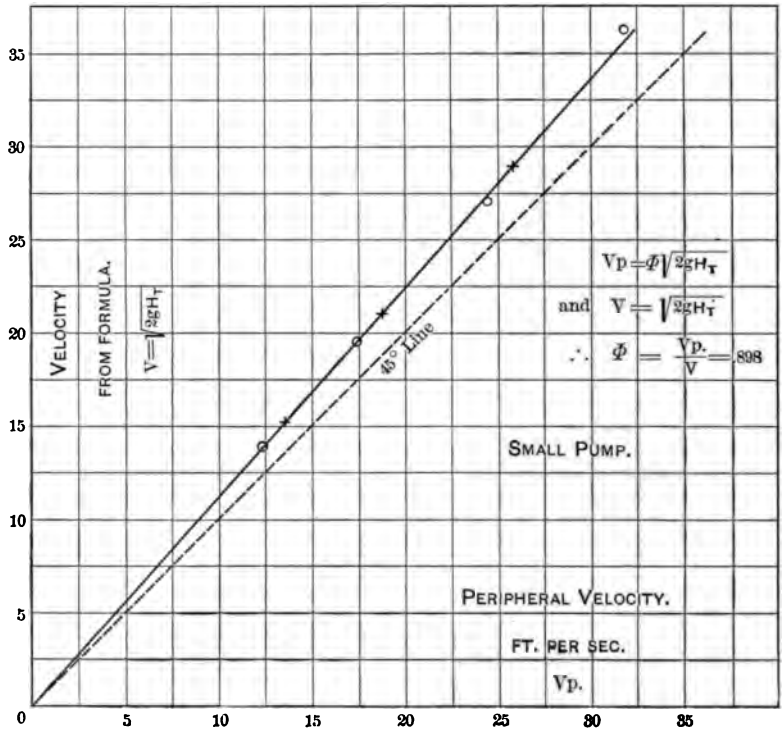

FIG. 86.

of a throttled discharge, by a mercury manometer at the valve near where water was discharged.

In the case of small pumps with low velocities of water passing through them, H_v and H_f become comparatively small quantities.

The first pump tested was rather small, having a 2½-inch suction, and discharge bushed to 2 inches; impeller, 5.14 inches in diameter. In the discharge pipe were one 45-degree and six 90-degree elbows, which made a bad showing for efficiency.

The pump was mounted on a cradle dynamometer. There is nothing peculiar in the construction of the dynamometer, except

that the flexible joints were obtained by means of strips of thin spring steel after the manner of the Emery Testing Machine.

The revolutions per minute were obtained by taking the time for 1,000 revolutions, with a stop watch reading to fifths of seconds.

The motor used was a gas engine which received an impulse every second revolution; at high speeds each impulse could be noted by the slight change of readings at manometers. Care was taken to have the readings as nearly the average as

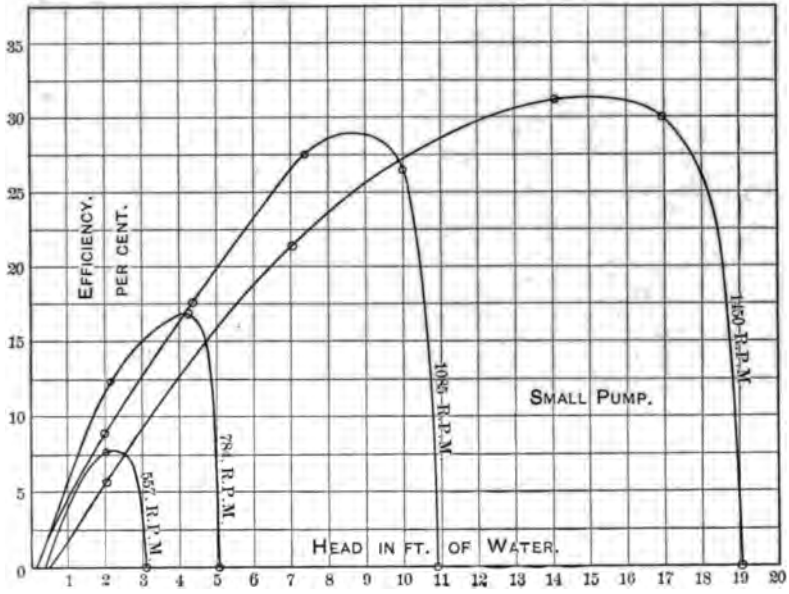

FIG. 87.

possible; in spite of this, the results were not all that could be wished for. The water was measured by means of a small weir, its constant having been obtained by calibration. Different speeds were obtained by means of cone pulleys on shafts between engine and pump.

The curve (Fig. 86) is plotted with abscissæ, peripheral velocity in feet per second, and ordinates the theoretical velocity from formula $V = \sqrt{2gH_t}$.

H_t is the total static head which pump maintains at the known peripheral velocity V_p.

Now $$V_p = \varphi\sqrt{2gH_t},$$

and $$\varphi = \frac{V_p}{V}.$$

From the curve it will be seen that $\varphi = .898$.

The four values of H_t which were plotted were taken from the observations with discharge valve closed; these are shown as small circles. The crosses show results obtained by attaching a hose and elevating discharge until water refused to run out at a known speed of revolution for pump, and then measuring the difference of water level between suction and discharge.

The curves shown in Fig. 87 explain themselves.

An attempt has been made to show three variables on a plane; these are better shown by a solid. If templates be made the size of these separate curves, and placed along a third axis at distances proportional to number of revolutions per minute, a solid may be constructed by filling in between the curves. In this way the manner in which revolutions, head, and efficiency vary may be shown. Such a model has been constructed.

The general form of the curves of efficiency for a centrifugal pump shows conclusively that there is a proper speed at which pump should be run for a given lift and maximum efficiency.

The pump described above is a part of the equipment of the Mechanical Laboratory of Tulane University of Louisiana.

LOG OF TEST OF SMALL PUMP.

Number.	Discharge Valve.	Manometers, Inches of Mercury.		Head Shown by Manometers, Feet of Water.	Revolutions per Minute.	Peripheral Velocity, Feet per Second.	Head Due to Peripheral Velocity H_t.	Static Head Pumped against in Feet of Water H_s.	Velocity of Water in Feet per Second.	Velocity Head H_v.	Friction Head. $H_f = H_t - (H_s + H_v)$.	Dynamometer Horse-power.	Hydraulic Horse-power.	Efficiency, per Cent.	Cubic Feet per Second, Water Pumped.
		Suction.	Discharge.												
1..	Closed	1.60	.65	3.04	556	12.48	3.00	3.10	0	0	−.04	.107	0	0	0
1..	Open	2.70	−.55	2.93	559	12.54	3.04	2.03	1.03	.046	0	.122	.013	7.54	.040
2..	Closed	2.55	2.20	5.86	774	17.37	5.83	5.03	0	0	−.03	.119	0	0	0
2..	Open	3.20	1.50	5.81	786	17.65	6.01	2.14	2.31	.083	.12	.187	.083	12.4	.095
2..	Throttled ..	2.75	2.00	5.86	792	17.80	6.11	4.23	1.29	.026	.22	.153	.035	16.71	.053
3..	Closed	2.65	6.85	11.23	1,087	24.38	11.45	10.90	0	0	.23	.211	0	0	0
3..	Open	4.35	5.15	11.11	1,091	24.50	11.58	2.00	3.65	.207	.26	.379	.189	8.98	.150
3..	Throttled .	3.90	5.65	11.29	1,091	24.50	11.58	4.35	3.14	.153	.14	.363	.166	17.62	.129
3..	" .	3.20	6.15	11.17	1,091	24.50	11.58	7.34	2.31	.083	.23	.287	.120	27.50	.095
3..	" ..	2.75	6.60	11.05	1,072	24.05	11.18	10.00	1.08	.018	.11	.191	.056	26.50	.044
4..	Closed	2.65	15.00	20.45	1,412	31.68	19.38	19.03	0	0	−1.07	.504	0	0	0
4..	Open	6.25	11.50	20.52	1,430	32.08	19.90	2.03	5.21	.423	−1.04	.907	.520	5.46	.215
4..	Throttled ..	5.50	12.30	20.50	1,463	32.80	20.80	7.01	4.60	.328	−.03	.704	.457	21.42	.189
4..	" ..	3.90	13.65	20.30	1,478	33.12	21.18	14.06	3.26	.165	.71	.680	.309	31.20	.134
4..	" ..	3.30	14.45	20.52	1,463	32.80	20.80	16.97	2.38	.088	.20	.631	.237	29.90	.098

Opportunity was offered, through the courtesy of Alfred Raymond, M.E., manager of the drainage system of New Orleans,

and W. M. White, B.E., assistant manager, to participate in a test of one of the large centrifugal pumps of the drainage system, located at Jourdan Avenue. This pump has an impeller 70 inches in diameter, with 26 inches width of blade at widest part, decreasing to 10 inches width at periphery, where there is a vortex chamber. There are double suction pipes 36 inches in diameter. The discharge pipe is 48 inches in diameter near pump, enlarging to 52 inches after passing discharge valve. The pump has its shaft horizontal, and is direct-connected to a vertical triple-expansion engine, whose cylinders are 13 inches, 21 inches, and 34 inches in diameter; stroke, 24 inches.

FIG. 88.—PITOT'S TUBE.

Engine and pump are placed several feet above the discharge level, so that the pump has to be primed by means of a steam injector, and must be run at a rate of speed which is above the most economical rate to prevent the water from being pulled out by gravity.

In the test the water was pumped down until the head pumped against was approximately 2 feet; then a series of readings were taken, including indicator cards from engine, beginning with a high number of revolutions and decreasing speed by decrements to the lowest possible, for that head. In this way the head was kept practically constant for a set of observations. The canal was then pumped down another foot, and observations taken as before. This was continued throughout the range of ordinary

lifts for pump. Manometer readings were not taken with first set of observations.

It will be seen that the results of this test may be plotted as a solid also. The three variables are as before, head pumped against, velocity, and efficiency; but in this case the head was kept constant and the variation of efficiency with velocity was noted, while in the case of the small pump the constant for a set of observations was the velocity of rotation, and the variables, head and efficiency.

The quantity of water to be measured, in the test of the large pump, was great. A weir would be too expensive, and was not

FIG. 89.—CALIBRATION OF PITOT'S TUBE.

to be thought of seriously. It was decided to use a Pitot's tube (Fig. 88) to measure the velocity of the water in the discharge pipe. The tube used is the property of Tulane University. It consists of a nozzle about 3 inches long, with $\frac{1}{8}$-inch hole, screwed into a $\frac{1}{4}$-inch tee, into the top of which is screwed a short $\frac{1}{4}$-inch nipple. Back of this tee is another of the same size, a solid iron plug connecting the two.

There are three $\frac{1}{8}$-inch holes in the sides and bottom of the latter tee, and another short $\frac{1}{4}$-inch nipple screwed into its top, while the opening opposite the nozzle is plugged.

Above the short $\frac{1}{4}$-inch nipples $1\frac{1}{4}$-inch pipes were used. These were made to slide through holes in an 8-inch cap, which latter acted as a guide and prevented vibrations, allowing read-

ings to be taken at any point along a vertical plane, which was a diameter of the discharge pipe, to within a few inches of top or bottom. Several readings were taken for each observation, usually at points one foot apart, starting at the top and going down by increments of one foot, then returning to the top by the same increments. The average of these readings was used for a final reading.

The calibration of the Pitot's tube (Fig. 89) was accomplished by fastening it to an outrigger in the bow of a small skiff, and drawing it along a canal at a known velocity for 500 feet. For this purpose a wire, 600 feet long, was stretched along the canal so that a running start and a space at end of the run could be obtained. Small ropes, attached to the skiff and to pulleys running on a wire, held the skiff in true course.

The skiff was pulled along the canal, at a uniform velocity, by men on the bank of the canal. Two observers were in the skiff, one to read h—the difference of level in the two glasses of the Pitot's tube—and one to take the time in passing over the 500 feet.

CALIBRATION OF PITOT'S TUBE.

Number.	Direction.	Velocity. Feet per second.	Difference. Height of water, h.	Velocity, $V = \sqrt{2gh}$.	$\psi = \frac{II}{IV}$
	I	II	III	IV	V
1	Up	4.87	Prepara	tory read	ing.
2	Down	4.92	.519	5.78	.854
3	Up	4.87	.486	5.64	.863
4	Down	5.25	.605	6.24	.842
5	Up	6.17	.759	6.98	.884
6	Down	3.45	.273	4.19	.823
7	Up	5.07	.561	6.01	.843
8	Down	6.64	.965	7.87	.843
9	Up		Failed to	catch time.	
10	Down	6.81	1.049	.823	.830
11	Up		Tube stop	ped up.	
12	Down	6.55	.992	7.99	.820
13	Up	6.46	.890	7.57	.855
14	Down	Boat hau	ler fell	down.	
15	Up	6.58	.928	7.72	.852
16	Down	6.71	.972	7.91	.850
17	Up	4.89	.490	5.62	.869
18	Down	5.44	.622	6.32	.860

Average, .849.

It was suggested by Mr. White that if a third tube be tapped into the discharge pipe of the pump and the difference of level of the water in this pipe and the impact pipe of the Pitot's tube be used for $h_{,,}$ in the formula $v = c\sqrt{2gh_{,,}}$ that c should be unity; or, in other words, that the ratio of the velocity shown by above arrangement to the velocity as shown by the regular Pitot's tube ought to be the constant obtained by calibrating the Pitot's tube in the canal.

In the first case the ratio was .856 and in the latter .849.

Another method was used by Mr. White to measure the velocity of water in suction pipes.

It consisted of a small pipe, dipping into the water on the suction side, and another tapped into the suction pipe some distance above the suction water; both were brought over to the wall and connected to glass tubes, side by side, with tops joined and a way provided to draw water to a convenient height in the glasses after the manner of a Pitot's tube. This was done with both suction pipes. The water being raised until visible in both glass tubes showed a difference of level, when water was running in the suction pipes, which was proportional to the velocity head.

The suction pipes were always full of water, so that this "velocity gauge" could always be used; while the discharge pipe was not always full because the pump was considerably higher than the discharge level, and at low speeds water was not supplied fast enough to keep the pipe full. This rendered the readings of Pitot's tube worthless for low speeds of the pump.

By taking observations with Pitot's tube which were known to be with full discharge pipe, and by comparing them with the readings of "velocity gauge," a constant was obtained which was used to compute the true velocity from readings of "velocity gauge."

Before starting the regular test, the discharge valve was closed and the pump was run at four different speeds, each speed being kept constant long enough to obtain accurately

the revolutions per minute and the readings of manometers on suction and discharge as below.

	Inches of Mercury.			R. P. M.	Feet per Second.	
	I. Suction.	II. Suction.	III. Discharge.		Peripheral Velocity.	$V = \sqrt{2gH}$ H from Manometers.
1	10⅝	9	+2 3/32	82	25.02	24.82
	10 7/16	8 3/16	+2⅜			
2	10⅝	9⅜	+7 9/16	103½	31.60	31.21
	10½	9 1/16	+7 5/16			
3	11¼	9⅜	+8½	111½	34.03	32.61
	11¼	9⅜	+8¼			
4	11 3/32	9 3/16	+13⅜	126½	38.60	38.20
	10 5/16	9⅞	+13⅜			

These results plotted in the curve (Fig. 90) give a value for ϕ of 1.02, as shown. $V_p = 1.02\sqrt{2gH_t}$ to compute the total head corresponding to a given peripheral velocity.

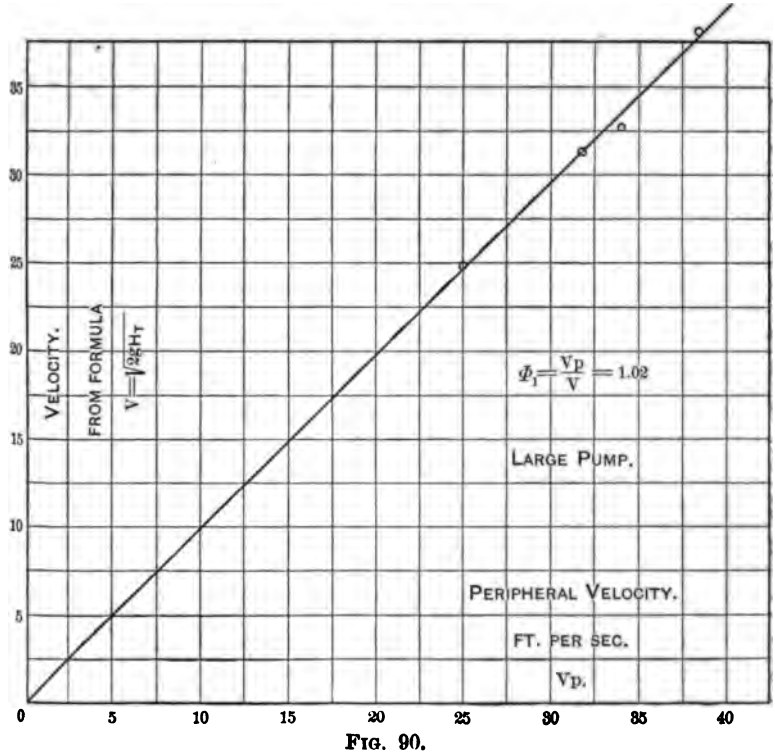

FIG. 90.

The curves of probable efficiency (Fig. 91) for the large pump were computed on the basis of 90 per cent. mechanical efficiency for the engine. The curves show quite regular results, except in the case of the curve for average head of 3.14 feet, which does not accord with the others.

An examination of the manometer readings will show that one suction pipe was partially stopped up, causing more water to enter on one side than on the other. This was likewise shown by the "velocity gauge." The values of ζ for observations

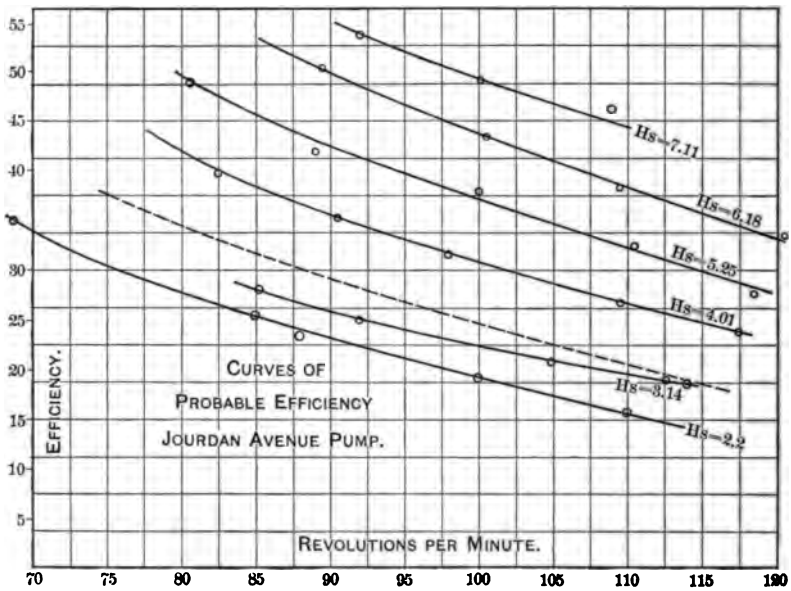

FIG. 91.

Nos. 7–11, inclusive, when one suction pipe was stopped up, are nearly constant and have an average value of 4.75.

Nos. 13–29, inclusive, with the exception of Nos. 16 and 22, which should be rejected, give an average value of $\zeta = 2.79$.

That is, with the pump taking considerably more water on one side than on the other, the loss of head within the pump is 4.75 times the velocity head, while, after water was allowed to run back and clear suction pipes, the loss fell to 2.79 times velocity head and remained practically constant.

The complete data are too voluminous to present in this paper. That the results are reasonably accurate seems probable when

LOG OF TEST OF LARGE PUMP.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Number.	Manometers, In. of Mercury.			Average (2) and (3) Feet of Water.	(4) In Feet of Water.	Head Shown by Suction and Discharge H_m.	Revolutions per Minute.	Peripheral Velocity V_p.	Head Due to Peripheral Velocity $H_1 = V_p^2 \div \phi^2 2g$.	Static Head pumped against H_s.	Velocity from Pitot's Tube $V = \sqrt{2g_a}$.	Velocity from Pipe in Discharge of Pump and Impact Side of Pitot's Tube.	Velocity from Velocity Gauge.	(13) ÷ (12).	(12) × .849 (ϕ).	(14) ÷ (12).	True Velocity (14) × .881 [Feet per Second].	Velocity Head H_v.	$(7) + (19)\ H_m + H_v$.	$H_f' = (10) - (20)$.	$\zeta = (21) \div (19)$.	Total Engine Horse-power.	Hydraulic Horse-power.	Efficiency Engine and Pump, per Cent.	Probable Efficiency of Pump, per Cent.	Water pumped Cubic Feet per Second.
	4.25 Ft. above Discharge.	Suction. 4.665 Feet above Discharge.	Discharge.																							
1	....	....	....	8.34	— 1.69	6.43	110	....	....	2.30	17.91	....	16.92	....	15.30	.808	14.90	....	....	....	....	985.9	54.76	14.18	15.75	221.0
2	....	....	....	8.34	— 1.69	6.43	100	....	....	2.30	15.56	....	....	....	13.30	.807	13.41	....	....	....	....	994.1	40.33	17.32	19.25	197.1
3	....	....	....	8.43	— 1.87	6.34	105	....	....	2.34	13.15	....	....	....	11.17	.803	11.38	....	....	....	....	200.2	42.60	21.57	23.63	167.2
4	....	....	....	8.12	— 1.77	6.75	85	....	....	2.30	12.47	....	11.95	....	10.57	.885	10.53	....	....	....	....	168.9	38.70	22.9	25.45	154.8
5	....	....	....	8.34	— 1.87	6.47	89	....	....	2.30	11.52	....	8.54	....	9.77	....	7.32	....	....	....	....	87.8	27.60	31.45	34.95	110.5
6	....	....	....	8.15	— 2.09	6.06	76	....	....	2.30	12.68	....	10.33	....	10.77	....	9.01	....	....	....	....	120.1	33.10	27.53	30.60	132.4
7	12.05	10.69	— 1.69	8.34	— 1.91	6.43	112.66	34.98	17.50	3.16	13.47	....	12.68	....	11.42	....	11.15	1.90	8.39	9.17	4.82	346.5	59.00	17.03	18.93	163.9
8	12.05	10.69	— 1.69	8.34	— 1.91	6.43	114	34.90	17.99	3.16	13.37	....	12.89	....	11.43	.877	11.30	1.99	8.41	9.58	4.84	358.0	59.60	16.63	18.50	166.1
9	11.62	10.50	— 1.87	8.43	— 2.12	6.34	105	32.03	15.23	3.14	12.14	....	11.54	....	10.30	.892	10.18	1.61	7.95	7.98	4.53	296.2	53.40	18.62	20.70	149.6
10	11.925	10.12	— 2.09	8.15	— 2.39	5.85	92	28.04	11.69	3.13	12.32	....	9.25	....	10.46	....	9.15	1.03	6.98	4.81	4.66	189.9	42.00	22.44	24.90	119.8
11	10.87	9.94	— 1.81	7.35	— 2.05	5.30	85.25	26.00	10.03	3.14	11.55	....	8.35	....	9.80	....	7.36	.826	6.02	4.01	4.90	150.1	38.05	25.30	28.10	106.7
12	10.62	....	....	....	....	....	76 (?)	23.17	7.06	3.12	9.94	....	6.61	....	8.43	....	5.52	.53	....	....	....	80 (?)	30.40	38.00	42.30	85.3
13	13.35	12.44	— 1.69	10.02	— 1.91	8.11	117.5	35.85	19.10	4.06	15.63	....	15.47	....	13.26	.870	13.44	2.81	10.92	.18	2.91	422.8	91.30	21.60	24.00	197.6
14	12.75	12.05	— 1.56	9.52	— 1.77	7.75	129.5	33.41	16.57	4.00	13.88	....	13.75	....	11.78	.857	12.11	2.28	10.03	6.54	2.87	335.8	80.95	24.10	26.80	178.0
15	12.19	11.50	— 1.87	8.87	— 2.12	6.75	94	29.87	13.36	4.00	12.03	....	11.71	....	10.30	.871	10.31	1.65	8.40	4.86	2.94	242.7	68.90	28.35	31.50	151.6
16	11.69	11.06	— 1.94	8.34	— 2.19	6.15	90.5	27.00	11.31	4.01	13.09	....	10.12	....	11.10	....	8.92	1.33	7.59	7.93	[8.19]	188.6	59.75	31.70	35.20	131.1
17	11.37	10.87	— 1.69	8.06	— 1.91	6.16	82.5	25.15	9.40	4.00	11.85	....	8.41	....	10.07	....	7.40	.85	7.01	2.80	2.81	198.0	49.45	35.80	39.75	106.8
18	14.59	12.97	— 1.42	11.07	— 1.61	9.43	118.5	33.15	19.42	5.21	15.38	....	14.44	.859	13.06	.904	12.72	2.51	11.97	7.45	2.96	444.0	110.80	25.00	27.80	187.0
19	14.06	12.75	— 1.73	10.65	— 1.96	8.69	110.5	33.75	16.92	5.21	13.30	....	13.49	....	11.30	....	11.88	2.18	10.87	6.05	2.77	353.0	103.40	29.30	32.60	174.6
20	13.50	12.32	— 1.66	10.03	— 2.10	7.93	100	30.52	13.82	5.34	12.37	....	11.40	.858	10.48	.913	10.03	1.60	9.53	4.29	2.68	357.0	87.00	34.30	38.00	147.0
21	12.84	11.91	— 2.12	9.48	— 2.12	7.36	89	27.39	11.05	5.28	11.87	....	10.41	[.877]	10.08	....	7.76	.94	8.30	2.63	2.80	171.1	64.50	35.70	39.80	116.1
22	12.37	11.53	— 1.85	9.00	— 1.91	7.59	80.5	24.53	8.95	5.31	....	....	6.53	....	7.59	....	5.75	.51	8.10	.85	[1.67]	113.7	59.62	44.00	48.90	81.5
23	15.32	13.91	— 1.31	11.05	— 1.48	10.47	130.5	36.75	20.01	6.30	15.19	....	13.96	....	14.91	.880	12.89	1.83	13.13	2.67	13.14	452.0	136.00	30.10	33.60	193.0
24	14.75	13.41	— 1.69	11.42	— 1.90	9.51	109.5	33.41	16.35	6.26	13.52	....	12.85	.855	11.48	.893	11.32	1.99	11.50	5.05	2.54	342.3	118.40	34.60	38.50	166.2
25	14.16	12.97	— 1.78	10.82	— 2.01	8.80	100.5	30.65	13.94	6.17	11.31	....	10.85	[.861]	9.60	....	9.56	1.42	10.23	3.72	2.62	262.1	98.40	39.05	43.40	140.7
26	13.44	12.62	— 1.91	10.23	— 2.15	8.07	89.5	27.39	11.05	6.10	....	....	8.33	....	....	....	7.35	.82	8.80	2.16	2.64	162.7	73.80	45.40	50.50	106.7
27	14.84	14.06	— 1.69	12.17	— 1.91	10.26	109	33.25	16.40	7.10	12.77	....	12.01	....	10.82	....	10.95	1.86	12.12	4.38	2.30	310.1	129.80	41.80	46.50	160.9
28	14.41	14.16	— 1.94	11.64	— 2.15	9.49	100	30.52	13.83	7.11	10.54	....	8.79	.834	8.95	.885	8.92	1.33	10.71	3.11	2.53	239.5	106.00	41.30	49.35	131.1
29	14.06	13.66	— 2.11	11.15	— 2.38	8.77	92	28.03	11.69	7.11	....	....	8.36	.856	....	.881	7.36	.84	9.61	2.06	2.48	181.1	87.45	48.30	53.50	108.2
Average																										

the regularity of efficiency curves is considered and the values of the constant *c*.

The writer wishes to acknowledge indebtedness to John Y. Snyder, B.E., of Shreveport, La., for assistance in testing the small pump, and to Messrs. Raymond and White in testing the large pump.

DISCUSSION.

Mr. Wm. O. Webber.—The writer is at very much of a loss to fully understand just what Mr. Gregory is trying to get at.

By Appold's formula for velocity the revolutions per minute of any centrifugal pump are obtained by the equation $\frac{(\sqrt{H} \times 500 + 550)}{Cf}$, in which Cf represents the circumference of the disk in feet. The writer found on the more improved pump that he designed that the formula could be reduced to $\frac{(\sqrt{H} \times 400 + 350)}{Cf}$. The average of Gregory's experiments shows that his formula was $\frac{(\sqrt{H} \times 500 + 450)}{Cf}$, so that the pump should have been between Appold's pump and the writer's.

In the writer's previous articles on this subject (vols. vii. and ix. of the *Transactions*), he shows that in any well-designed centrifugal pump, where the data and observations are made with a weir, or other means by which the amount and height to which water is elevated can be accurately determined, the efficiencies of such pumps increase up to a velocity through the discharge aperture of about 10 feet per second, with the exception of a 10-inch Heald & Scisco pump, which decreased.

The writer has, therefore, plotted the tests of the 48-inch pump from the data given by Mr. Gregory (Fig. 92), the vertical divisions representing the efficiency, and the horizontal divisions the gallons per minute and velocity in feet per second, through a 48-inch aperture—all of which show a decreasing efficiency of from 8.6 feet to 15.72 feet; but which also show a higher efficiency in the higher lifts than the lower lifts, which would correspond with the writer's experience, as he found the highest efficiencies to be at about 20 feet lift.

Also another table (Fig. 93), the vertical heights representing

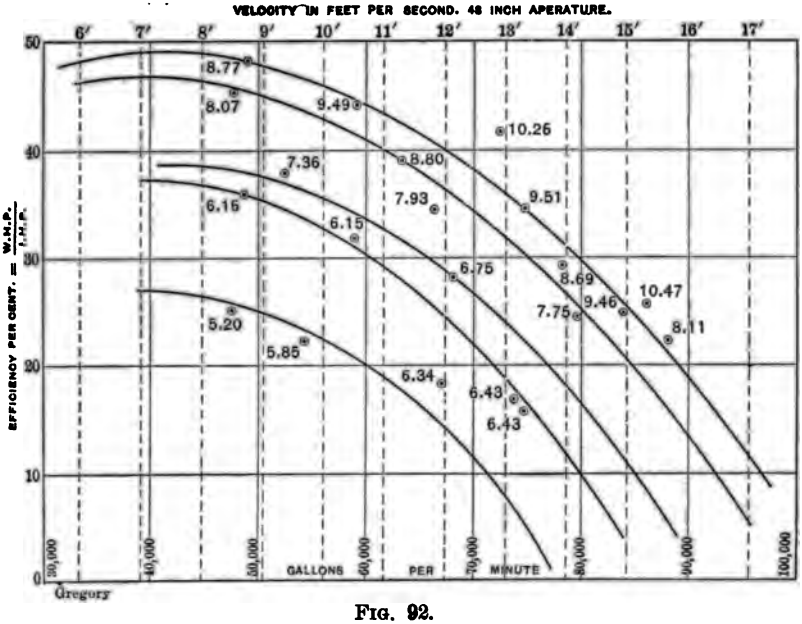
VELOCITY IN FEET PER SECOND. 48 INCH APERATURE.
6′ 7′ 8′ 9′ 10′ 11′ 12′ 13′ 14′ 15′ 16′ 17′
50
40
30
20
10
0
EFFICIENCY PER CENT. = W.H.P. / I.H.P.
8.77
8.07
9.49
10.26
7.36
8.80
7.93
9.51
6.16
6.15
6.75
8.69
9.46
10.47
7.75
8.11
5.20
5.85
6.34
6.43
6.43
30,000
40,000
50,000
GALLONS
60,000
PER
70,000
MINUTE
80,000
90,000
100,000
Gregory

FIG. 92.

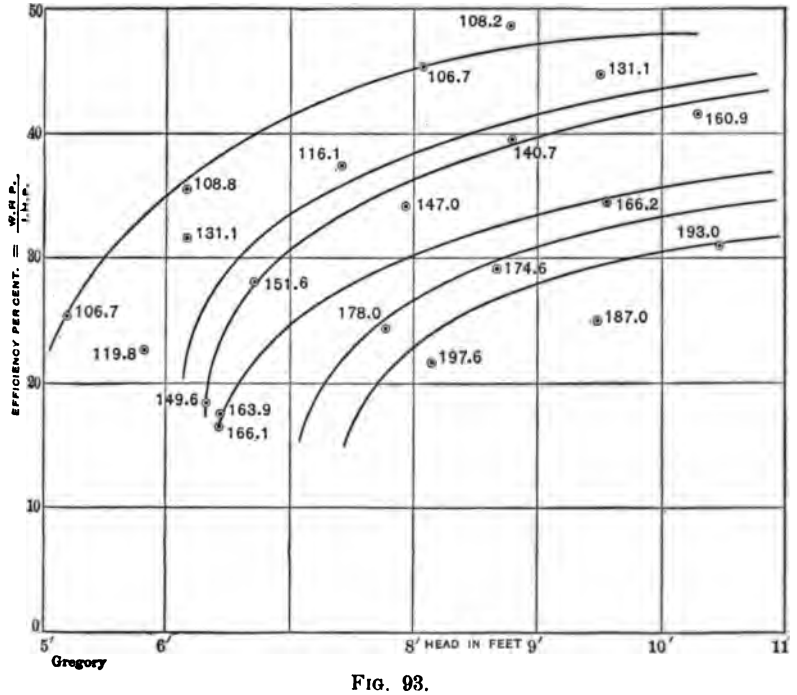
50
40
30
20
10
0
EFFICIENCY PER CENT. = W.H.P. / I.H.P.
108.2
106.7
131.1
160.9
116.1
140.7
108.8
147.0
166.2
131.1
193.0
151.6
174.6
106.7
178.0
187.0
119.8
197.6
149.6
163.9
166.1
5′
6′
8′ HEAD IN FEET 9′
10′
11
Gregory

FIG. 93.

efficiency, the horizontal divisions representing head in feet; and in this chart it shows that the efficiency is increasing with the head in feet, but decreasing in efficiency as the quantity of water increases—all of which would tend to show that the pump was running at too high a speed, giving too great a velocity in feet per second, and pumping entirely too much water to have given the best results.

The writer also thinks that the tests are open to criticism from the view that in tests No. 7 and No. 8, where the head is exactly the same, the velocity from the velocity gauge approximately the same, the hydraulic horse-power nearly the same, and the water pumped in cubic feet per second nearly the same, yet there is a difference of 11½ horse-power in the total horse-power required, which seems to show a lack of care in either taking or figuring out the indicator cards.

Mr. Gregory gives a chart showing the peripheral velocity of this pump, which varies from 25.02 to 38.60 feet per second. This, the writer has shown in his previous papers, is too high, as all of the best data on centrifugal pumps show that the best results are obtained at peripheral velocities not exceeding from 28 to 30 feet per second.

The writer would also criticise a series of tests where—as Mr. Gregory states—since the pump was considerably higher than the discharge level the discharge pipe was not always full, and at low speed water enough was not supplied to keep the pipe full. This, in the writer's opinion, would tend to efface tests made under these conditions. The writer has found by his experiments that it is always better to have a centrifugal pump discharge above itself, so as to keep a constant head on the pump and keep the pump case and discharge pipes full of water.

The writer would also criticise the curves of efficiency shown in Fig. 91, based on the revolutions per minute, which curves show an upward curvature, tending to give an infinite efficiency at no revolutions, which is absurd. The curves should bend the other way, because there must have been some speed below the points plotted in this table, at which the maximum efficiency was obtained, and below which number of revolutions per minute there would have been a falling off of efficiency.

The highest efficiencies which Mr. Gregory gets are stated by him as being "probable," and 53.50 is the highest figure he obtains for the pump alone, and 48.20 for the engine and pump;

and the average of his efficiencies is something in the neighborhood of 30 per cent.—all of which is very low, and would tend to throw a doubt on the results for so large a pump, even if it were of a very inefficient form of construction.

The writer does not think that the Pitot-tube method of measuring the discharge of the pump by velocity can be taken as sufficiently accurate from which to draw conclusions.

In his opinion, centrifugal pump tests to be of any use and at all reliable should either be made by pumping water to a known height and measuring it through a weir, or pumping it through a Venturi meter which has been carefully calibrated.

In some recent tests made by the writer on 30-inch pumps, at Albany, under a lift of 20.92 inches, the efficiency of the pumps and engine was 66.3 per cent., the revolutions per minute were 214, the quantity of water discharged was 9,550 gallons per minute, or about 212.8 cubic feet per second, and the net efficiency of the pumps alone 77 per cent.

At some later date the writer will furnish a complete log of this test—which was a 24-hour duty test—for the Society.

Mr. E. T. Adams.—The subject discussed by Mr. Gregory is very timely. Efficiencies above 70 can now be obtained with centrifugal pumps at heads ranging from the lowest up to heads limited more by the ability of the impeller to resist the stresses due to centrifugal force than by the height to which the water is to be lifted. It is not meant, of course, that 70 to 80 per cent. efficiency is always possible, regardless of head, cost, or the conditions under which the pumps must be operated; but I do mean that such efficiencies are possible, almost regardless of head, when the other conditions are favorable.

This naturally has led to the use of the centrifugal pump in many situations where formerly it was excluded by reason of its supposedly low duty, or because it was supposed that it was particularly inefficient at high heads.

In view of this, it is seen at once that the efficiencies reported are ridiculously low; 40 or 50 per cent. too low in the case of the large pump, and nearly 200 per cent. too low in the case of the small pump. Such low efficiencies are not typical of American practice, and is it not questionable whether any good purpose is served by their publication without such explanation as would enable the reader to determine whether it was the pumps or the methods of testing which were at fault? It is to be hoped that

Mr. Gregory will supply that adequate analysis of the losses, and the reasons therefor, which alone can make the records of value.

As Mr. Gregory has pointed out, much depends on the methods of testing, the location of manometers, and the like, and there are several points of this nature which the paper does not make exactly clear. For example, all the elbows on the discharge appear to be located beyond the manometers on the discharge. Of course this is correct, so far as location is concerned; but as a manometer so located would register all resistance beyond that point, why does the author state that these elbows "made a bad showing for efficiency"? Again, the manometer placed in the suction is advisable, since it insures uniform conditions and makes the efficiency of different pumps strictly comparable; but when placed as close to the pump as shown by Mr. Gregory, it will register almost anything between the true pressure head at that point and a pressure due to the forced vertex formed by the impeller. In cases which have come to the writer's notice, this pressure has amounted to several feet of water, and a manometer placed as shown in Fig. 90 has been used by the writer with fair success in getting an approximate value of the "velocity of whirl at inlet"; but when thus located, its use as a part of a scheme for determining the static head is of more than doubtful value. There is much corroborative evidence that the methods employed in preparing and conducting the tests are seriously at fault. Of course this may have been unavoidable, but it seems reasonable that the data presented should be complete enough to allow any member to judge accurately of this for himself.

The large pump tested was designed and built by a prominent California specialist in this line of work, and in the designer's account of it, published about three years ago in the *Engineering News*, it was stated that at 12-foot head, with 150 cubic feet per second capacity, the efficiency should be 65 per cent. This figure is rather low to be considered good practice now, but was excellent for that time; and it seems very probable from the figures presented in this paper that, when properly tested, it should give very nearly or quite the efficiency predicted. At velocities of 10 to 14 feet per second, the water flowing from a centrifugal pump is a very turbulent stream; and between weeds, eddies, cross currents, and entrained air, it is probable that quantity determinations by means of a Pitot tube are very far from being accurate. The pump, from the author's description, must be located at or near

the top of a syphon of which the suction is the longer and the discharge the shorter leg, and the tendency mentioned for water to be "pulled out by gravity" on the suction side should be balanced by a like tendency on the discharge side; and a more reasonable cause for the low quantity discharged at the heads and velocities given seems to be that the pump was not put in proper operating condition before the tests were made, and that the pump was taking in a very large amount of air.

Regarding the formulæ and the deductions made therefrom, it should be noted that $V_p = \phi \sqrt{2gH_t}$ bears on its face a statement of the conditions to which its use should be limited, and there is no evidence that it applies at all to the pump tested; and even if it does, it should be remembered that ϕ merely fixes the relation between the velocity of the rim of the impeller and the head due to the angular velocity of the water within the pump; ϕ has absolutely no other value, and cannot be used even to approximate this relation *after discharge begins*, when the mass of water rotating and its radius of gyration have become totally different from what they were when there was no flow through the pump. For this reason the method derived for determining the friction head must fail.

Mr. Gregory's paper bears evidence of a great amount of careful, painstaking work, and it seems unfortunate that this should be wasted on commercial tests of inefficient pumps when there is such a rich mine of important problems awaiting that careful original investigation which is more frequently possible in our engineering colleges than elsewhere, and for an example I need go no further than that problem which is the basis of all formulas relating to centrifugal pumps; namely, the velocity of whirl of the water as it enters the blades of the impeller. The formula which Mr. Gregory has used assumes certain conditions. The formula usually quoted assumes a different set of conditions; but beyond the knowledge that none of these assumptions is strictly accurate, little of real value is known, except fragments of experimental determinations made by various manufacturers, each of whom in self-defence hoards his own fragment of the whole truth.

The whole subject is rich in opportunity for original investigation, and it is to be hoped that Mr. Gregory will find opportunity for further work in this important field.

Mr. Albert F. Hall.—The writer would like to ask Mr. Gregory if he does not think the losses due to shock and eddies should be

considered in the total head H_t? In any measurements that may be made by means of a dynamometer we are unable to separate the hydraulic resistances from those of friction of bearings, etc. In order to obtain a correct understanding of the true action of all the resistances that occur in the centrifugal pump, much has yet to be done if we wish to design a wheel of the highest efficiency. The best work thus far published in English is the little paper by Professor Unwin. (*Proceedings of the Institution of Civil Engineers*, vol. liii., session 1877–1878, part iii.) The most extensive work, and one that has gone more deeply into the matter than any other known to the writer, is that by the Russian marine engineer, F. A. Brix, Moscow, 1896, of which the writer has a translation in manuscript. Other works by Dr. Gustave Zeuner; Dr. Richard Mollier; Professor Brauer; Edmond Marchand Bey, who has some novel ideas; Professor Lindner; Paul Farcot; Professor Grove; J. Buchetti, and many others whose works are in the hands of the writer, have discussed this question with more or less differences in detail, yet, to a certain extent, they have all followed a beaten track, and left the matter, so far as any real practical results go, in a very unsatisfactory state. Too little is known regarding the resistances at the entrance to the wheel. All authors assume the blades to end at the inner circumference, and the direction of the path of water at this point radial, thus ignoring all questions that arise before this point. At the exit from the wheel proper little is considered, except in some cases, and the design of the volute and the passage from this to the discharge pipe proper is only lightly considered. It would appear that unless more thorough experiments are made than have heretofore been attempted, we shall only be able to design a centrifugal pump by mere guessing. It will not do to praise or condemn any experiments on record, because the data furnished are very meagre. It will not do to express an opinion upon the form of the blades unless we accurately know all the other conditions, and there are many. Mr. Brix has analyzed very thoroughly the path of the water through the wheel, and has not confined his attention to action at the inner and outer circumferences. He has also shown a geometrical method for designing the volute. Mr. E. Marchand Bey has discussed, more than any other author, the question of entrance, and Dr. Mollier has some novel points on the influence of the width of the wheel. Professor Abel has also written some valuable

matter. Could all of these various writers be collated and systematized, and combined with a few well-conducted experiments, we should certainly be able to put the matter into better shape than now exists. As it is, the subject is one of mere guesswork, notwithstanding the claims of various builders.

Prof. D. S. Jacobus.—The method of testing the small pump does not seem to be a proper one. It appears to me that it would be impossible to guard against eddy action at the lower end of the suction pipe, which might produce a lateral force, and that the effect of the reaction of the water in the exit pipe could not be eliminated, and that either of these actions might affect the readings of the dynamometer.

In some tests made a short time ago by Mr. H. S. Wood, of the Atlantic, Gulf and Pacific Company, at the Stevens Institute, where he was granted the facilities of the laboratories, methods were adopted that gave results of great accuracy. Several different forms of pump runners, both open and closed, were tested, as well as different forms of cases. The pumps were driven by an electric motor which was mounted on a Webb floating dynamometer. The dynamometer registered the total power applied to the pump. The water was pumped from a suction tank at about the pump level to a second tank mounted above the pump. The water delivered by the pump was not throttled to produce a working pressure, but the tank into which the water was pumped was mounted at the height of the working head. The working head was made about 60 feet in one series of tests, and 17 feet in another. The water pumped was returned to the suction tank until the pump ran uniformly, after which it was collected for a given time in a second tank, this second tank being graduated so that the rate of flow could be determined. Both the suction and discharge pipes were 5 inches in diameter. The horse-power required to drive the pump varied from about 8 to 25. The results of the tests agreed very well among themselves, the efficiencies for duplicate tests varying, as a maximum, 1 per cent. from the average; the average variation was about ½ of 1 per cent.

It appears that the author of the paper in computing the efficiency of the small pump has used the manometer readings, whereas with the large pump he has used the static head in place of the manometer readings. The static head is the proper quantity to employ, and the efficiencies for the small pump, being

computed from the manometer readings, are, therefore, not comparable with those which he gives for the large pump.

The point has been well taken that there are not enough data given to show exactly how certain results are derived.

I agree with the last speaker that the method of obtaining the friction head is not correct. I am at present making some experiments of my own in this line.

Mr. Wood, of whom I have already spoken, is present, and he is the one who designed the large pump referred to in the paper. With your permission I would like to have him called on to make a few remarks. Can this be done?

The President.—We would be pleased to hear Mr. Wood.

Mr. H. S. Wood.—Professor Jacobus is not exactly right in stating that I designed the pump. It was the whole plant. John Richards, of California, as has already been mentioned, I believe, is responsible for the exact curvature of the pump in detail, and guaranteed to us, as a firm, an efficiency under the specification conditions of 65 per cent. In explanation, however, of the shortcomings of the conditions under which those experiments were conducted, I can state that the pump was designed for 12 to 18 feet head, with the maximum efficiency nearer the larger head than the smaller. The specifications also required that the contractor should conduct experiments to the satisfaction of the city engineer on the efficiency of said pump. When, however, it came to arranging for those experiments, the enormous capacity of the pump proved a stumbling block. There was neither money nor space nor time to construct a weir to handle 150 cubic feet per second, which was the specification capacity of that pump at the specified lift. Therefore, the next best system had to be searched for. It was at first thought that we might get along with a current meter introduced through a hand-hole or man-hole in the top of the discharge pipe. The speed of the discharge current, for commercial and other reasons, had been assumed to be about 10 to 11 feet per second, and even that required a 52-inch pipe, although the pump discharge at the case was only 48 inches, expanding to 52 by a tapered section. We found that the velocity was entirely beyond the capacity of any current meter obtainable to safely register without wearing out its bearings. We got an expensive one, and utterly ruined it in short order. We had also taken up the question of the Venturi meter, here suggested by one of the speakers. On consultation with the experts on the

Venturi meter, we found that the velocity of discharge was entirely beyond reliable registration by said meter. Had we had 5 or 6 or even 7 feet a second, they would have undertaken the task, although it would have been very expensive. Consequently, as a last resort, practically, in order to enable the contractor to show some result and to get his pay, if he deserved it, from the city, the Pitot tube was suggested, and the Pitot tube was used; and had the conditions of lift been within the specification limits, there might have been some reliable results obtained with the Pitot tube if properly calibrated. As a fact, however, on account of the season of the year, and the level of the water in the drainage canal inside of the levees leading to this pumping station, and the natural level of the discharge surface without the levee (which is the level of Lake Pontchartrain, and of the Gulf of Mexico), the lift, instead of being 12 feet minimum, or 18 feet maximum, was only about 2 feet and a fraction, as this paper indicates. Now who would expect a pump designed for 12 to 18 feet lift to show any prophesied efficiency at 2-foot lift? Consequently, we as contractors placed no reliance, and we as engineers placed no reliance, upon the measure of efficiency of those tests. Since then we have gone fully into the question of comparative merit of pump cases and runners of different design, and in these tests, with the coöperation of Professor Jacobus, we secured a great many valuable points and information on the comparison of different pump cases and runners —not the absolute, but the comparative, because the constant of frictional loss at high speeds and heads had to be the same for all, and was not separately determinable.

One more point about the manometer readings at New Orleans. So uncertain was the pressure in the discharge pipe, and, we believe, in the suction pipe, that at one place where we had cut a hand-hole to insert the Pitot tube, some 10 or 15 feet beyond the discharge orifice of that pump—such were the irregularities or reaction curves of pressure due to the change from centrifugal to tangential motion in the water, that the 6-inch diameter open hand-hole showed absolutely at that particular point no tendency for the water to exude. Water could be seen flowing up to the top of the pipe, running along underneath this 6-inch opening in the top of the pipe and not exuding therefrom; while a few feet from that hole, where we cut through other experimental holes, the water spurted in the way to be expected in a natural condition. I think, therefore, it will be seen that the actual circum-

stances rendered the observations almost worthless at that particular time, and under those particular conditions, on that particular pump.

Mr. Wm. Kent.—I am especially interested in this paper for the reason that some of the experiments and deductions in it constitute the best experimental proof that I have yet seen of the inaccuracy of the formula quoted in the last line of the first page of the paper. That is the time-honored formula $V = \sqrt{2gH_t}$. It is a perfectly correct theoretical formula when the velocity is produced by the head, but it is incorrect when the head is produced by the velocity; and the proof of the last statement is shown in the paper in the most satisfactory way I have ever seen. The formula on the fourth page is $V = \varphi\sqrt{2gH_t}$, in which V is the peripheral velocity of the wheel, H_t the total static head, and φ a certain coefficient, which experimentally the author finds to be .898. By transposition we find that the H in this formula equals $1.24\frac{V^2}{2g}$. That is, the head produced by the given velocity of the impeller is 24 per cent. greater than the head which should be theoretically produced, if the formula $V = \sqrt{2gH}$ is correct. This means that if we consider the peripheral velocity to be the cause, and the head the effect, then the effect is greater than the cause, which is absurd. The only conclusion, then, is that the formula is wrong, and that the theoretical formula should be $V = \sqrt{gH}$ or $H = \frac{V^2}{g}$, and the experimental result is $H = 0.62\frac{V^2}{g}$. That is, the actual head is 62 per cent. of what would be theoretically the head, provided there were no eddies or obstructions. Take the Pitot tube. Several writers on the Pitot tube have said that the proper formula for it is $V = \sqrt{2gH}$, but the experiments in this paper prove that it is not correct. The correct theoretical formula is $V = \sqrt{gH}$ or $H = \frac{V^2}{g}$, and the correct practical formula is $H = c\frac{V^2}{g}$, in which c is an experimental coefficient, always less than unity, whenever the head is the effect produced by the velocity. I have never seen a better statement of how to test the Pitot tube than the one given in the paper. I do not know a better method than to put one in a canal where there is no current, and tow it in a boat at a uniform velocity. The author

obtained in his experiment $V = 0.849\sqrt{2gH}$, which transposed is $H = 1.39\frac{V^2}{2g}$, or 39 per cent. greater than the head, which many writers on the Pitot tube say is the theoretical head that can be produced by the velocity. If we take the correct formula we obtain $H = 0.695\frac{V^2}{g}$, in which 0.695 is the coefficient of efficiency of the tube. The difference between 0.695 and unity is the loss of head in the Pitot tube, due to eddies, or to the currents not striking it squarely, and being deflected at right angles to its orifice. It is well known that the pressure produced by a jet striking a blade at right angles to the jet is theoretically equal to twice the head which would produce the velocity, or $2 \times \frac{V^2}{2g}$. We would get the same result on the Pitot tube, provided the jet would strike it fairly and leave at right angles, which it does not do. As one of the speakers said, we can have no confidence in the Pitot tube unless it is standardized every time it is used. The Pitot tube thus standardized would be an excellent instrument for testing the velocity of water flowing at a uniform speed. But in no current, stream, or pipe is there such a thing as uniform velocity of water; so that, even if you have the Pitot tube properly standardized, the next question is how to use that and get the average velocity of the water through the pipe. That is a matter of great difficulty, and has to be done by taking the velocity at different points of the area, and making a computation by the aid of the calculus, to find the average velocity.

This theoretical formula $H = c\frac{V^2}{g}$ applies to centrifugal pumps, Pitot tubes, centrifugal fans, and windmills, and generally to all cases in which the velocity of a current is the cause, and the head is the effect; while $V = \sqrt{2gH}$ is the correct formula where the head is the cause, and the velocity the effect.

*Mr. W. B. Gregory.**—The purpose of this article was to describe two tests, together with the methods used, in order that the discussion would bring forth the best thoughts of those members who have given special attention to this type of pump.

On the part of the representatives of the Drainage Commission, the test of large pump was undertaken to determine, among other

* Author's closure, under the Rules.

things, the most economic speeds for pump at given lifts. By reading gauges, showing the level of canal into which section pipes dip, and level of canal into which pump discharges, the engineer in charge of the station can know, by referring to the curves, Fig. 87, the speed at which pump and engine must be run to give best economy.

On the part of the writer, the test was undertaken to prove certain theories and obtain what he hoped would be valuable data in regard to centrifugal pump, Pitot's tube, etc.

Mr. Webber has given a formula for the large pump, and, after comparing it with Appold's formula and that of the more improved pump designed by himself, has come to the conclusion that the pump should have been between Appold's and his own. Presumably he refers to the efficiency of the pump. After plotting curves of his own, he arrives at conclusions which were drawn in the original paper. The curves for large pump "show a higher efficiency at the higher lifts than at the lower lifts"; also "the pump was running at too high a speed, giving too great a velocity in feet per second, and pumping entirely too much water to have given the best results." This confirms the writer's statements on page 267 of paper.

The criticism of observations Nos. 7 and 8 is entirely out of place. The results are plotted in Fig. 87 as the two lowest points in the curve having an average value of $H_e = 3.14$ feet. It stands to reason that results which plot in as smooth curves as those shown, and particularly the two observations referred to, are probably correct. If there is any error, it is one that runs throughout the entire test, and the probabilities are all against it.

Undoubtedly Mr. Webber is right in having a centrifugal pump discharge above itself, so as to "keep a constant head on the pump and keep the case and discharge pipe full of water." Under such conditions the speed of pump could be reduced until a velocity corresponding to maximum efficiency could be obtained. This plant had to be tested as it was, so far as elevation was concerned, however it had been carefully overhauled and all air leaks stopped previous to the test.

Mr. Webber says that the curves of efficiency (Fig. 91) are "absurd," as they bend in the wrong direction—that they would tend to give an infinite efficiency at no revolutions. This is not the case, and would have been shown experimentally had it been

possible to run the pump at lower speeds. The reason why low speeds could not be obtained has already been stated; had it been possible to obtain points on curves at lower revolutions they would have risen still higher, reversed their curvature near maximum efficiency, and then fallen rapidly to zero. The zero point in each curve would be that point where the head due to peripheral velocity would just equal the lift or static head.

Before discussing efficiencies, it might be well to inquire which efficiency is meant, or, rather, what quantities are to be credited to a pump in computing its output. The writer cannot believe that Mr. Adams has meant the same efficiency as that used in this paper. Three possible efficiencies will be stated; viz., commercial efficiency, in which the work given out by pump is obtained by taking the product of actual feet in difference of level of suction and discharge and pounds of water pumped. Secondly, where the pump is given credit for pressures which exist in suction and discharge pipes near the pump, these pressures being obtained by mercury manometers or accurately calibrated pressure-gauges. In this case, the pump is given credit for friction head in suction and discharge pipes and head lost by water entering suction pipes. Thirdly, what might be called mechanical efficiency; in which, in addition to the quantities just mentioned, the pump is also credited with the velocity head, or, in other words, the kinetic energy remaining in the water due to velocity of discharge.

In the case of the small pump, the head pumped against was the sum of difference of level of suction and discharge, and the head, in inches of mercury, reduced to feet of water, which was shown at the end of the discharge pipe just back of a valve used to throttle discharge. This was a different manometer from those near the pump, where they were placed on suction and discharge quite near the pump, as engraving of small pump shows. The power put in was obtained from a cradle dynamometer. If we credit the pump with the head shown by manometers near it, as proposed in the second scheme for efficiency, we shall find that the third observation from bottom of log of test of small pump will give an efficiency of 62.5 per cent. which is very good for so small a pump. The peripheral velocity for this observation was 32.8 feet per second.

The statement was made in the original paper that elbows and small pipe (2 inches) in the discharge of the small pump made a bad

showing for efficiency. The known lengths of pipe and the commonly accepted coefficients for loss of head in elbows and pipe will give, by computation, about 11.3 times the velocity head as the head due to friction. An application of Bernouilli's theorem to experimental work gave a value which agreed almost exactly for loss between point on discharge near pump and point near end of discharge pipe. It will be seen, from this fact, that it was impossible to obtain a velocity head having any but small value. This will explain why the curves of small pump are so pronounced, and the head between zero and maximum efficiencies so small. Had the discharge been short and without elbows, the curves would have been very different.

To return to the large pump—if we take observation No. 29 we have 8.77 feet, the head shown by the manometers near the pump. To compute efficiency according to the second scheme mentioned, we have hydraulic horse-power $= \frac{8.77 \times 108.2 \times 62.3}{550} = 107.3.$ $107.3 \div 181.1 = .593$, the efficiency of pump and engine. $.593 \div .90 = .67$, the probable efficiency of pump.

Again, if we compute efficiency according to third scheme, we will have to add to 8.77 the velocity head .84; then we have hydraulic horse-power $= \frac{9.61 \times 108.2 \times 62.3}{550} = 117.5.$ $117.5 \div 181.1 = .65$, and $.65 \div .90 = .72$, which corresponds to the ideas expressed by some of the critics.

It must not be forgotten that pump was running at too high a speed and was pumping against a much lower head than that for which it was designed.

The writer is of firm conviction, in spite of the remarks of Mr. Adams, that manometers near the pump, say twice the diameter of the pipes on which they are placed, from the pump casing, either on suction or discharge, will give true readings of static head. Fig. 86 shows that the small circles which were plotted from values of head, read in inches of mercury, are quite as reliable as those measured by elevating discharge pipe and taking actual measurements in feet of water, such as observations plotted as crosses. The writer believes this to be true when water is running through pump, for by taking the sum of head shown by manometers and velocity head for small pump, and obtaining the theoretical velocity from this head by means of the formula $V = \sqrt{2gh}$ and plotting results as in Fig. 86, all points will be

found to coincide with, or be very close to, the line already drawn. In this case no account is taken of friction head lost by water passing through the pump, and sufficient refinement could not be had in experiment to show it; but as friction head is a constant times velocity head, and velocity head is always very small in comparison with total head, the error in disregarding it is small. Subsequent tests by students have checked the accuracy of the test given and have shown the point just referred to even better than in this test.

In spite of the criticism of the formula $V_p = \phi\sqrt{2gH_v}$ and the method of finding friction head in the case of the large pump, the fact remains that this test worked up on that basis gave very reasonable results. It does not necessarily follow that since the head produced by a given peripheral velocity, according to this formula, is greater than the theoretical head due to that velocity "the time-honored formula is wrong. At any rate, it makes no difference with practical results in this case; the above equation merely expresses a relationship which has been found true experimentally. From the head due to peripheral velocity the sum of static and velocity heads was subtracted, and the remainder, which has been called friction head, was found to be a constant times velocity head. None of the gentlemen who criticized this work gave any proof of error, if any exists. This point was not an after thought brought out in working up this test, but the test was undertaken with the idea in mind of proving this point.

In regard to this friction head it seems to the writer to be best explained by a consideration of Bernouilli's theorem. At points in the suction and discharge near pump, manometers show static heads. The measurements of water for continuous flow give velocity and velocity head. Between these points is a source of head; viz., the impeller of pump. Knowing the head corresponding to a given peripheral velocity of impeller, the heads at manometers, and the velocity head, the loss must be due to friction and possibly impact, etc., between these points. Such a loss of head would occur if water were flowing through pump and impeller not moving. This does not account for all the losses in the pump, for there will be the friction of bearings, which will be small, and the friction of sides, if impeller disk revolves against the water, which will not be shown by the friction head referred to.

The writer believes that by this method one hydraulic loss may be separated and studied. Doubtless this friction head is some-

what influenced by the shape of impeller blades. By using this method, that loss, together with the water entering the impeller, could be studied.

Some designers, in experimenting with different shaped blades, have assumed that the shape which gave the greatest head for a given peripheral velocity was the best in every way. It does not follow that this is true, as the shape of blade which gives the greatest head may be the one in which the friction losses are greatest.

The fact that the discharge pipe was not always full at the place of inserting the Pitot's tube does not affect the results obtained, because it does not follow that the pump was not full of water when the discharge pipe was not full at a distance of about 20 feet from pump. It was stated in the paper that the readings of the Pitot's tube were not used whenever the discharge pipe was not full; in fact, the velocities used as the true velocities were obtained from the velocity gauge; but the constant to be used with the velocity-gauge readings was obtained by a comparison of those readings with those of the Pitot's tube for observations where discharge pipe was known to be full; column 17 gives this comparison; where omitted, discharge pipe was not full.

In order that the amount of variation in readings of Pitot's tube and velocity gauge may be shown, sample readings of both will be given for observation No. 20. From observed head, velocity was computed by means of formula $V = \sqrt{2gh}$ in each case; constants were introduced later, as indicated in log.

Velocities from Pitot's tube and velocity gauge.

Pitot's tube.	Velocity gauge.	
	I.	II.
11.88	13.10	9.92
12.10	13.20	10.09
11.75	13.08	10.07
12.20	12.96	9.80
12.65	12.88	9.60
12.85	12.90	9.60
12.62	12.98	9.76
12.25	12.90	9.80
12.10	av. 12.99	9.80
av. 12.27		av. 9.82

Average 12.99 and 9.82=11.40.

These readings were taken simultaneously, and those shown are fair samples. It will be seen that the velocity in the two suction

pipes was unequal, according to readings of velocity gauge; this will help to account for a part of the friction loss as the water passes through the pump.

That Pitot's tube and velocity gauge measurements are correct and reliable was recently shown at the tests of one of the large pumps at station No. 6 of the New Orleans Drainage System. These pumps have impellers about 9 feet 6 inches in diameter and discharge pipe 8 feet in diameter. The Pitot's tube used in the test described, and a velocity gauge arranged in a similar manner, were used as a check on measurements of water discharged through a flume of known cross-section, the velocity being obtained by means of a velocity meter of the revolving vane type, which was slowly moved across the flume near the water level, then lowered and moved across again, the process being repeated until the total section of flume had been crossed at definite intervals and the mean velocity thus obtained.

In this case Pitot's tube was used in the suction pipe of the pump. It was found that both tube and velocity gauge agreed with results obtained from flume and velocity meter very closely, the maximum difference being about 3 per cent., and under favorable conditions the difference being less than 1 per cent. The amount of water measured was more than 250 cubic feet per second.

The water measurements in connection with test described in original paper have been elaborately written up by Mr. White in the *Journal of the Association of Engineering Societies*, vol. xxv., No. 4, October, 1900.

Mr. Kent states that if the formula $V = \phi \sqrt{2gh}$ be assumed for Pitot's tube, the efficiency of this tube is greater than unity, and therefore absurd. The peculiar form of the tube may cause a suction due to eddy currents about the holes in the back section of tube; and, while the impact side gives the head due to velocity, the suction on back section of tube may be added to the reading. As stated in the paper, when a pipe was brought up from a hole in the side of a 52-inch discharge pipe of pump, and used with impact side of tube, the formula $V = \sqrt{2gh}$ was found to hold almost exactly, the error being no greater than that usually allowed for error of observation. This is not conclusive evidence, but experiments on various shapes of tubes would show whether the time-honored formula is to be discarded.

Mr. Kent would state the formula $V = \sqrt{gh}$ as theoretically correct. If this is true, a properly designed Pitot's tube ought to

demonstrate it. If we must always use a constant and express the formula $V = \phi\sqrt{gh}$, why not merely write it $V = k\sqrt{h}$ where k is a constant? No proof has been given of the incorrectness of the formula $V = \sqrt{2gh}$, or of the correctness of the formula $V = \sqrt{gh}$.

In conclusion, let us hope that in the near future experiments will establish the truth or error in the formula which lies at the very foundation of hydraulics, and in a way which will be conclusive. The writer expects to build a Pitot's tube and test it exactly as the tube described was tested, seeking new light on the subject.

The suggestion of Mr. Hall, that the various writings on the subject of centrifugal pumps should be collated and systematized, and combined with a few well-conducted experiments, is most timely. Mr. John Richards has written me of a centrifugal pump in Europe, used to raise water 460 feet high, capacity 5,000 gallons per minute. The subject is growing in importance each day, and is receiving more and more attention. Combined, well-directed effort might accomplish much.

No. 878.*

HARDNESS, OR THE WORKABILITY OF METALS.

BY W. J. KEEP, DETROIT, MICH.
(Member of the Society.)

A TEST of the workability of a metal will not distinguish between hardness, which blunts a tool, and tenacity, which makes it difficult for a tool to remove a portion of the material.

A punch pressed into the surface of a metal is hindered by both these properties.

Prof. Thomas Turner constructed a machine which indicated hardness by the scratch of a standard octahedral diamond across a polished surface. Gram weights were placed on the diamond until a scratch could just be seen as a dark line on a bright surface. The number of grams was the degree of hardness. This is the most practical test for metals too hard to be cut with a drill, such as chilled and white cast iron.

In the *Transactions* of this Society, vol. v., p. 140, Prof. Thos. Egleston described a machine for testing hardness by the use of a weighted drill, which he afterwards abandoned.

In 1897 Mr. Chas. A. Bauer, unaware of any former experiments along this line, arranged an ordinary drill press as a test of hardness. He used a hand-made flat $\frac{3}{8}$-inch drill, with 160 pounds pressure, with a speed of 250 revolutions per minute.

A revolution counter records the number of revolutions of the drill required to penetrate a test bar exactly $\frac{1}{2}$ inch after the lips are under the surface. This apparatus has been in constant use since that date, and is a practical success. Fig. 94 shows this machine.

I arranged with Mr. Bauer to make such machines for the market, using an autographic diagram for a record instead of the number of revolutions.

When I had constructed a machine, I found that with an

* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

ordinary drill press the varying friction of the working parts influenced the diagram. With a drill penetrating the top of a

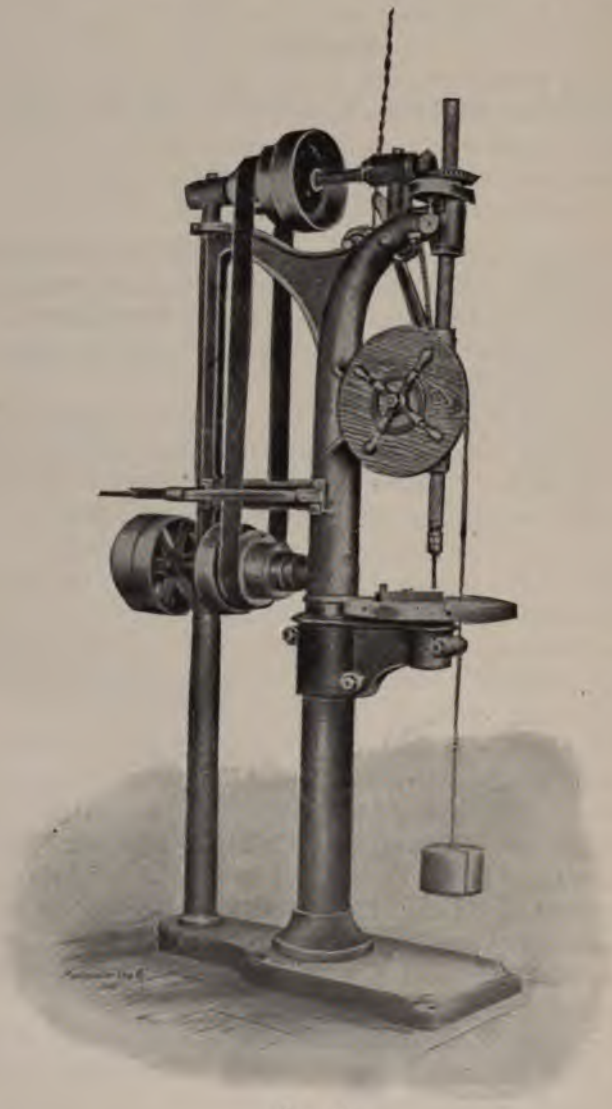

FIG. 94

test bar, the hot chips remaining in contact with the drill drew the temper of the extreme edge. A horizontal machine developed more defects than the vertical form.

After repeated failures, I placed all of the working parts below the table, making the drill enter the under side of the test specimen, and not giving the drill any vertical motion.

Fig. 95 shows this machine. A table, with a vertical motion, has the test bar clamped on its upper surface over a ½-inch central opening, which receives the point of the drill. Four rods attached to this table pass downward, and are attached to an iron weight near the floor. Loose weights, from ½ pound to 10 pounds—50 pounds in all—are added, making the whole load on the drill point 150 pounds.

The test specimen is weighed, and an equal amount of removable weight is taken off.

The downward movement of the specimen is transferred by a steel ribbon to an arm moving on ball bearings, the end of which carries a recording pencil, which multiplies the record five times. To allow this pencil to act directly on the paper, a table is provided, with a curvature equal to the path of the pencil, and which is moved at right angles to the mark made by the pencil by means of a screw driven by a worm on the drill spindle. 100 revolutions of the drill move the paper 1 inch; ⅛-inch penetration moves the pencil 1 inch.

Scale of Hardness.—As the diagram will be a diagonal between a 90-degree line and the base line described by the pencil before the drill moves with an ordinary transparent protractor, the angle that the diagram makes with the base line is the degree of hardness. The line at 90 degrees, the limit of the machine, is the hardness of any material that the drill cannot penetrate.

The speed of the drill is 200 revolutions per minute, to prevent heating under all conditions. A variation of speed does not materially vary the diagram.

TABLE I.

Number Revolutions of Drill.	100	200	300	400
First test.....	45.1 degrees	44.6 degrees	43.9 degrees	43. degrees
Second test.....	29.1 "	30. "	29. "	28.6 "
Third test.....	27.9 "	27. "	28.4 "	—

The specimen and its weight hang on the point of the drill practically without friction. They move so freely that it is

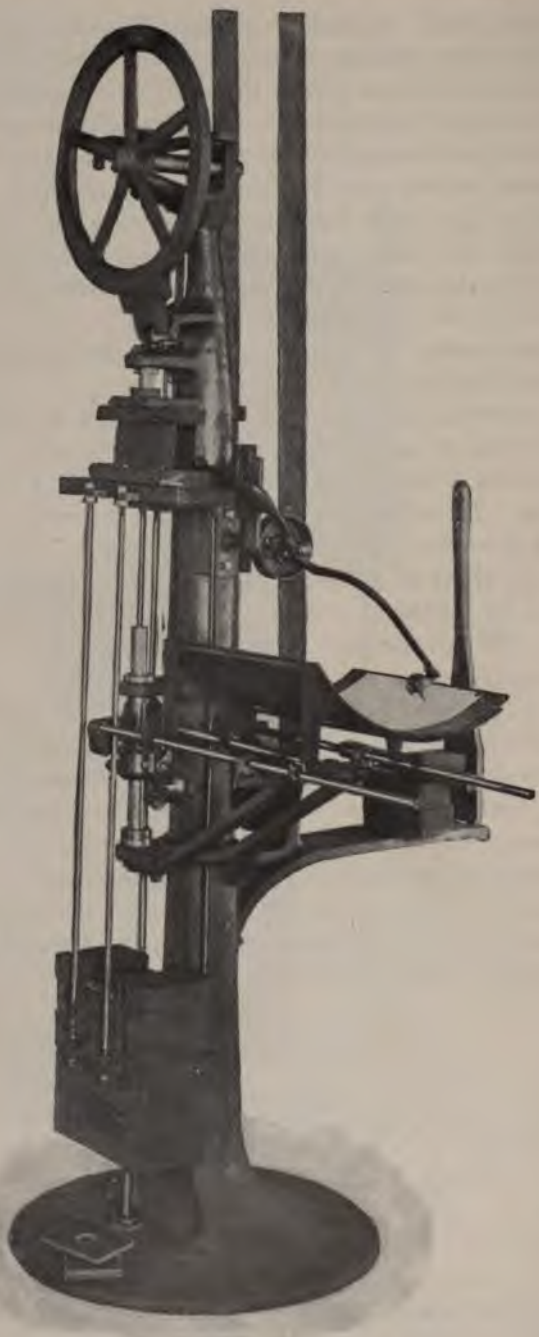

Fig. 95.

necessary to apply a slight friction to the ball-bearing to prevent a vibration of the pencil point.

A Variation of Load would materially influence the diagram. 100 pounds gave 45 degrees; 125 pounds, 38.4 degrees, and 150 pounds, 32.9 degrees. A trip is set to stop the drill at any desired depth of hole. The machine is started by a clutch. By a pinion and rack, which is disconnected while drilling, the table with specimen is raised or lowered at will by a hand wheel at the upper part of the machine, with friction applied to its rim, which will support the 150-pound load.

Drills.—I found that a straight, fluted drill made a better diagram than a twist drill, and would wear better. The Cleve-

FIG. 96.

land Twist Drill Co. guarantees to make drills for this purpose of uniform temper and shape. I grind the heel of the drill away, so as to leave the lips $\frac{1}{16}$ inch thick and the shape of an ordinary flat drill.

The straightway drill gave 25 degrees, and the twist drill 29 degrees, but probably the difference in clearance would cause this. The straightway drill ground to 10 degrees gave 77 degrees; given a very little clearance, but the heel still touching, gave 59 degrees; with heel ground away like a flat drill gave 30 degrees.

Grinding.—I found that a dry wheel would draw the temper from the extreme cutting edge, and that the ordinary grinders would not make each lip cut alike. I therefore made the very simple wet grinder shown in Fig. 96.

The angles of the drill are those recommended by the drill-

makers, and in using the machine all drills are to be ground on this grinder.

The grinding does not, however, make very much difference. Drill sharpened by grinder, all angles exactly alike, and both lips taking the same chip, gave 30 degrees; drill sharpened by hand, 31 degrees, and ground so that only one lip cut, gave 30.8 degrees.

Entering the Drill.—If the drill is started on a flat surface it enters more rapidly at first, making the first part of the diagram a curve, showing the hardness of the skin of the casting, or else the influence of the scale on the lips of the drill. The test bar may be pickled to remove the scale, but in any case the cutting edges will be blunted by the grit in the surface. Entering through the ordinary sand scale of a 1-inch square cast-iron test bar, the drill gave a diagram clear through the bar of 39 degrees; but the same drill resharpened, and in a hole alongside with the scale ground off, gave 32.5 degrees.

I, therefore, countersink with a $\frac{1}{2}$-inch drill until the lips are nearly into the surface. Entering, the test drill in this countersink begins with a full cut, and shows the hardness of the metal uninfluenced by local and varying conditions. (I use the term "hardness" when I mean workability of the metal, or abrasive resistance.)

For experimental work, as for this paper, the drill is ground after drilling each hole; but if the surface is first removed, for shop use this is not necessary. The following records were made by drilling holes in the same bar in succession $\frac{1}{2}$ inch deep without resharpening; the surface was ground clean: 25.6, 25.5, 25.8, 26.5, 25, 25, 26.8, 26, 27, 27.5, 26.9, 27, 27, 27.2, 27, 26.3, 26.8, 25.6, 27, 25.5 degrees, the last being the same as the first.

The same bar, with the drill sharpened after each hole, gave 27.6, 26.5, 26.2, 25.5, 26.2, 26.5 degrees.

In another bar of another iron, sharpening each time, holes near together, gave 28.5, 28.2, 30.8 degrees.

Spongy spots in castings, though called sand holes, usually do not contain grit, and do not injure the drill; as soon as sound metal is again reached the original diagram is resumed.

Fig. 97 shows such a diagram from a bar $\frac{1}{2}$ inch square, and another diagram from a hole alongside, where the metal was all sound. The first diagram is from a bar containing hard spots

and soft spots. The drill strikes a hard spot that it cannot cut, even after regrinding.

When the metal is nearly too hard to cut, the edge becomes dulled. In a sample of almost white iron the drill penetrated $\frac{3}{10}$ inch at 61 degrees, then 90 degrees, resharpened and in the same hole $\frac{1}{8}$ inch at 61.5 degrees, then 90 degrees, sharpened again, $\frac{1}{32}$ inch at 82 degrees, then 90 degrees, again sharpened, $\frac{1}{8}$ inch at 62.8 degrees, then 90 degrees.

In a test bar of series 1, Iroquois, $\frac{1}{2}$ inch square (the first

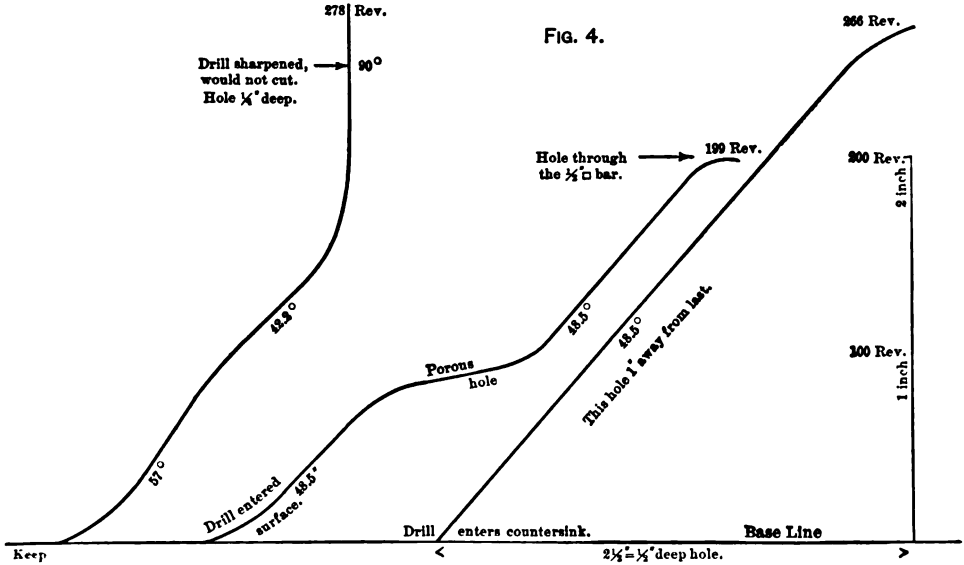

FIG. 4.

FIG. 97.

diagram in Fig. 97 is another hole in this bar), near the ends there were no hard spots, but near the centre the fracture was full of white spots. The drill entered 58.5 degrees; at $\frac{1}{20}$ inch deep struck a hard spot, about $\frac{1}{40}$ inch thick, 84 degrees; then for $\frac{1}{8}$ inch soft, 49.1 degrees; then hard, 65 degrees.

Another hole alongside, $\frac{1}{10}$ inch deep, at 51 degrees, then 90 degrees, resharpened and in same hole 63 degrees, then 74 degrees, then 82 degrees, then a soft spot, 64 degrees; then 75.2 degrees, then 90 degrees, resharpened and 90 degrees, would not penetrate farther, and hole only $\frac{2}{8}$ inch deep. A soft metal, on account of its toughness, will sometimes give a larger record than a harder metal. A test bar from tea-chest lead gave

4 degrees, because the metal was simply crowded into the flutes of the drill, but block tin gave clean chips and was 1.1 degrees with 150 pounds on the drill, and 2 degrees with 100 pounds. An alloy of 90 parts aluminum and 10 parts tin gave 10.5 degrees with 150 pounds, and 16 degrees with 100 pounds. A test bar of soft copper gave 47 degrees, while a bronze, with 90 per cent. copper and 10 per cent. aluminum. gave 21 degrees, and a bronze, with 9 per cent. aluminum, gave 23.8 degrees, though it was softer than the 10 per cent. metal. The copper was soft but tough. A bar of Jessups steel gave nearly the same diagram as purchased and after annealing in lime.

A rolled bar of puddled iron gave 63 degrees; a cast bar of Bessemer steel (with no manganese), 73 degrees; a bar from grain nickel, 77 degrees.

Three sets of ½-inch square test bars were made at three different times—one bar in dry sand moulds; one bar in sand as ordinarily moistened for green-sand moulding, and the third bar in sand so wet that water would run out.

TABLE II.

	First Set.	Second Set.	Third Set.
Dry sand.....	25 degrees.	28 degrees.	29.5 degrees.
Ordinary sand	26 "	30 "	29 "
Very wet sand.....	29 "	29 "	33 "

Drillings for Chemical Analysis.—This machine is especially made for this purpose. A tray slides under the table, and the drill passes through a revolving disk between the tray and the under side of the table, having a rubber packing around the drill. Around the hole on the upper surface of the table is a gutter to catch any dirt or sand, and the raised edge around the hole makes a close joint with the test bar, the under surface of which is free from sand on account of the counter sink.

The disk revolving with the drill catches all the drillings and throws them to the sides of the tray, mixing them thoroughly, and all particles of dust are saved. The tray fits dust tight under the table. When these drillings are placed in a marked envelope they are free from all outside matter and should be used as a whole and no parts selected with a magnet. Chemical analysis would interpret the hardness diagrams. Everything

about the machine being practically invariable, except the hardness of the test piece, the size of the drillings will vary with the hardness, and therefore there will be a standard of uniformity that is most desirable. For laboratories not having power the machine is driven by hand.

Hardness and Chemical Composition.—According to general opinion all of the chemical elements found in cast iron harden it. Carbon and manganese certainly do. Sulphur causes the carbon to be combined and thus hardens. Phosphorus does not influence carbon, but hardens. Silicon hardens cast iron, but it causes carbon to change from the combined state into graphite and thus becomes a softener. A white iron that cannot be cut, by an addition of silicon becomes mottled or gray and can be cut. Hard iron softened by changing combined carbon, becomes tough as it becomes soft, and in a test of workability this modifies the record which otherwise might show the influence of chemical composition.

Tables III. and IV. show the record of shrinkage, and the record of hardness of each size of test bar made in 1894 for the Society's committee on methods of testing.

The sizes were ½ inch square, 1 inch square, 2 inches × 1 inch, 2 inches square, 3 inches square, and 4 inches square. There were nineteen series of these bars. It was intended to vary the silicon in series 1 to 6 and 7 to 12 to give 1.00 per cent., 1.50 per cent., 2.00 per cent., 2.50 per cent., 3.00 per cent. and 3.50 per cent. The other seven series were from various foundries and their ordinary mixtures. The holes for hardness were made alongside those from which drillings for analysis were originally taken. Gray cast iron suitable for machinery castings is usually uniform in hardness throughout a test bar. The 20 holes drilled an inch apart along a test bar 24 inches long and 1 inch square varied only 2 points in 27 degrees.

In one bar from Bement, Miles & Co.'s heavy machinery iron, 2 inches × 1 inch, three holes one inch apart were 32.2, 33.2, 32.3 degrees, but in a bar from series 17, 3 inches square, one hole gave 44 degrees, and 1¾ inches distant the drill would not cut at all. I have already shown that near the ends of a ½-inch square bar of series 1, the iron was soft, and near the centre the bar was full of hard spots. A hardness diagram shows exactly the character of the metal taken from the hole. In one ½-inch square bar a spiral hard spot was encountered which did

not make an irregular diagram, but could be seen on the walls of the hole.

Each of these test bars was analyzed in triplicate in 1894 by Messrs. Dickman and Mackenzie, 1224 Rookery Building, Chicago, Ill. The records are in *Transactions*, 1895, beginning on page 1099.

TABLE III.

HARDNESS—NINETEEN SERIES, A. S. M. E. TESTS.

Kind of Iron.	Calculated Silicon.	No. of Series.	½ in. sq. × 12 in.	1 in. sq. × 24 in.	2 in. × 1 in. × 24 in.	2 in. sq. × 24 in.	3 in. sq. × 24 in.	4 in. sq. × 24 in.
"Iroquois," with silicon added by "Pencost" ferro-silicon.....	1.00	1	58°	41°	34°	28°	28°	27°
	1.50	2	34°	30°	37°	32°	28°	28°
	2.00	3	33°	31°	32°	27°	27°	20°
	2.50	4	36°	32°	39°	30°	20°	25°
	3.00	5	31°	29°	26°	27°	24°	32°
	3.50	6	33°	33°	32°	21°	30°	28°
"Hinkle" and "Pencost".....	1.00	7	62°	28°	30°	25°	30°	26°
	1.50	8	29°	32°	30°	33°	24°	27°
	2.00	9	30°	23°	31°	32°	28°	30°
	2.50	10	31°	31°	28°	30°	30°	33°
	3.00	11	32°	27°	22°	19°	22°	22°
	3.50	12	24°	19°	24°	19°	23°	21°
Michigan Stove Co.	Actual Average.							
	2.82	14	35°	28°	25°	23°	24°	38°
	3.18	13	34°	23°	25°	19°	27°	37°
	3.50	15	29°	26°	25°	23°	28°	33°
Car-wheel iron.....	0.77	19	90°	41°	37°	36°	32°	30°
Light machinery.....	1.76	16	38°	37°	34°	38°	24°	27°
Heavy machinery.....	2.06	18	45°	33°	32°	31°	28°	28°
Air furnace for malleable iron.....	0.89	17	90°	90°	90°	90°	44°	39°

TABLE IV.

HARDNESS—SERIES D AND E, A. F. A. TESTS.

Series.	Kind of Mould.	½ in. sq. × 12 in.	1 in. sq. × 12 in.	1½ in. sq. × 12 in.	2 in. sq. × 12 in.	2½ in. sq. × 12 in.	3 in. sq. × 12 in.	3½ in. sq. × 12 in.	4 in. sq. × 12 in.
D, Chill Roll.	Green sand.	90°	90°	90°	39°	35°	38°	30°	33°
	Dry sand...	90°	90°	90°	39°	33°	37°	36°	36°
E, Sand Roll.	Green sand.	90°	90°	90°	61°	38°	33°	36°	33°
	Dry sand...	90°	90°	90°	55°	36°	40°	37°	31°

TABLE V.

SHRINKAGE—NINETEEN SERIES, A. S. M. E. TESTS.

Kind of Iron.	Aver. Per c't. Silicon.	No. of Series.	½ in. sq.	1 in. sq.	2 in. × 1 in.	2 in. sq.	3 in. sq.	4 in. sq.
"Iroquois," with silicon added by "Pencost".....	0.80	1	.183	.160	.148	.131	.116	.102
	1.21	2	.172	.150	.138	.125	.110	.106
	1.88	3	.166	.145	.130	.109	.069	.039
	2.01	4	.162	.143	.123	.099	.066	.128
	3.19	5	.157	.105	.094	.075	.067	.057
	3.04	6	.161	.130	.086	.077	.085	.033
"Hinkle" and "Pencost".....	.93	7	.176	.149	.144	.139	.115	.072
	1.17	8	.160	.145	.126	.122	.093	.092
	1.67	9	.156	.141	.134	.128	.083	.036
	2.23	10	.154	.124	.092	.094	.075	.067
	2.71	11	.157	.102	.090	.062	.053	.023
	3.50	12	.144	.098	.092	.068	.043	.023
Michigan Stove Co..	2.82	14	.148	.098	.083	.072	.063	.035
	3.18	13	.130	.095	.091	.079	.072	.052
	3.50	15	.123	.094	.096	.091	.078	.032
Car-wheel iron.....	0.77	19	.238	.153	.142	.144	.126	.115
Light machinery.....	1.76	16	.171	.151	.143	.129	.100	.069
Heavy machinery.....	2.06	18	.161	.139	.120	.091	.067	.042
Air furnace for malleable iron.....	0.89	17	.248	.247	.221	.201	.157	.144

TABLE VI.

SHRINKAGE—SERIES D AND E, A. F. A. TESTS.

Series.	Shrinkage, Dry Sand Bars.	½ in. sq.	1 in. sq.	1½ in. sq.	2 in. sq.	2½ in. sq.	3 in. sq.	3½ in. sq.	4 in. sq.
D	Av. silicon, .085 Dry sand	.280	.270	.220	.160	.140	.140	.130	.110
E	Av. silicon, .072 Dry sand.....	.230	.180	.170	.160	.150	.140	.130	.110

Table IV. gives the hardness of Series D and E, chill roll iron and sand roll iron, made for the Testing Committee of the American Foundrymen's Association, of which Dr. Richard G. G. Moldenke is chairman.

Tables V. and VI. give the shrinkage of the same test bars, which indicates the influence of silicon in each of the bars in presence of the influence exerted by each of the other chemical elements in the iron, and the influence of slower cooling as the test bars increase in size.

Series 17 and Series D are very similar, both being from iron refined in an air furnace. Irons high in combined carbon are liable to have soft and hard spots near together, and in these and such series, as 19, 1, and 7, the analysis of drillings taken from a single hole may not represent the average metal.

Therefore, as the hole for hardness is not the same hole for analysis, some allowance should be made for variation in composition. The variation in shrinkage, which is a mechanical analysis of the influence of all elements and conditions, shows that outside of chemical composition unknown conditions influence the physical quality of cast iron. The same, or other conditions, may influence hardness.

Hardness seems to follow combined carbon very closely, but seems to be modified by other elements or conditions. And it is a question whether toughness does not increase the records from the gray bars. This sensitive machine makes it possible to study the workability of metals in relation to chemical composition.

Before closing I will give a few more examples.

TABLE VII.

INFLUENCE OF ANNEALING ORDINARY GRAY CAST IRON.

	Shrinkage.		Chill.	Strength.		Hardness.		Analysis by Dickman and Mackenzie.						
	½ In. Sq.	1 × ½.	½ In. Sq.	Dead Load.	Deflection.	One End ½ In. Sq.	Other End ½ In. Sq.	TC.	GC.	CC.	Si.	P.	S.	Mn.
No. 1 bar not annealed	.155	.169[2]	.14	435	.28	30.8°	28.5°	3.77	3.32	.45	1.78	.505	.041	.568
No. 3 bar not annealed	.154[2]	.172[2]	.14	415	.27	31°	29°							
Average	.156	.171	.14	425	.27[2]	29.9°								
No. 2 bar before annealing	.157	.166[2]	.14											
No. 4 bar before annealing	.155	.169	.14											
Average	.156	.167	.14											
No. 2 bar after annealing	.096	.069	.06	400	.36	19°	18.9°	3.77	3.68	.05	1.78	.510	.043	.568
No. 3 bar after annealing	.095[2]	.070	.08	400	.34	19°	19°							
Average	.096	.069[2]	.07	400	.35	19°								

The bars were packed in wood shavings in an iron box heated to a white heat in 12 hours, and allowed to cool for 24 hours. Re-

ducing combined carbon to four-fifths has reduced hardness one-half. I took a pig of "Iroquois," and in a crucible furnace added silicon by the same "Pencost," as in Series 1 to 6 (which were melted in a cupola). The results were: 1.00 per cent. silicon, 30 degrees; 1.50 silicon, 32 degrees; 2.00, 34 degrees; 2.50 silicon, 36 degrees; 3.00 silicon, 33 degrees; 3.50 silicon, 24 degrees. Adding to same "Iroquois" phosphide of iron, 1.00 P., 35 degrees; adding 86 per cent. ferromanganese, 1.00 Mn., 34 degrees.

This shows that the hardness of the ferrosilicon, or ferromanganese, or phosphide, is added to the iron, and not necessarily that the silicon, phosphorus, and manganese in this case produced the hardness. The 11.00 per cent. ferrosilicon (Pencost) was very deficient in carbon. The 10 per cent. phosphide of iron contained no carbon, and therefore reduced TC still more, while the 86 per cent. Fe.Mn. contained 6.00 per cent carbon.

Table VIII. is a record of test bars ½-inch square by 12 inches long, made in a crucible from pigs of iron which contained the holes from which the drillings for analysis were taken. The chemical composition would be changed by remelting in a crucible and cooling in a green sand mould of test bars ½-inch square.

TABLE VIII.

	Dead Load.		Shrinkage.	Chill.	Hardness.	Total Carbon.	Graphite.	Combined Carbon.	Silicon.	Phosphorus.	Manganese.
	Strength.	Deflection.									
Ensley gray forge.....	368	.20	.185	.25	.48	3.14	2.21	.93	2.62	.88	.16
Summerlee, No. 1, f'dy..	377	.17	.165	.65	.33	3.38	2.92	.46	2.00	1.27	1.07
Tuscarawas, No. 2, f'dy..	418	.24	.154	.30	.33	3.62	3.18	.44	1.93	.70	.86
Napier, No. 3, foundry...	423	.19	.165	.80	.37	3.65	3.50	.15	1.76	.85	.48
Eureka, " 3, " ..	443	.25	.159	.45	.37	3.45	2.90	.55	1.54	.83	.23
Ashcand, No. 3, f'dy.....	352	.15	.156	.50	.58	3.33	3.12	.21	4.70	1.54	.96

These results, taken as a whole, and especially those of increasing silicon by crucible heats, suggest that each car of pig iron should be tested for hardness. A mixture can then be made which will give soft castings. They seem to indicate that a car of iron may have what would be considered an ideal chemical composition, but that a hardness has been imparted to it during manufacture which is imparted to the casting.

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Special care needs to be taken to procure silicon carriers which shall be soft in the pig.

It is a question whether the close and sometimes uneven grain which much of the pig iron sold on analysis shows will not prove to be hard iron.

As a test of pig iron can be made in fifteen minutes before a car is unloaded, without any test bars, perhaps pig iron may be sold on a guaranteed hardness.

A broad field for inquiry is presented.

DISCUSSION.

Mr. John L. Bacon.—Mr. Keep makes a test on a sample by boring through, or partly through it. This does not seem to be a fair test for the actual workability of the metal, for this reason: a casting is made up, we might say, of three layers—first, the hard outside scale; next, a coating or layer of metal softer than the scale, but denser and harder than the inside, or soft centre; this soft centre being the third layer.

When a casting is being *machined*, it is the first two layers that are ordinarily worked, not the inside softer part, which gives the "angle line" in Mr. Keep's diagrams.

Now, after removing the scale, the work of machining is done on the second dense layer of material, and for machining qualities it is this part that should be tested. It seems practically impossible to do this by drilling through a piece; as the metal to be tested lies within, say, $\frac{1}{8}$-inch of the surface, and the point of a $\frac{1}{2}$-inch drill will have penetrated through the $\frac{1}{8}$-inch of metal by the time the lips of the drill are cutting, the hole must be continued still deeper before a line is drawn long enough to obtain the required angle. Now, when this angle *is* obtained, it is the angle indicating the hardness of the softer central part of the casting, and not the hardness of the harder metal close to the surface, which latter is the metal removed in machining.

Since receiving a copy of Mr. Keep's paper, I constructed the apparatus shown in Fig. 98, in order to follow out his tests. The rear cap on the tail stock of one of the engine lathes in the machine shop at Lewis Institute was removed, leaving the spindle projecting as shown. The other end of the spindle carried a small chuck holding a drill such as described by Mr. Keep in his tests. The drill in this case was $\frac{5}{8}$-inch diameter. The piece to be tested was bolted on the face plate as shown.

A bar of wood about $2\frac{1}{4}$-inches square was placed behind the projecting end of the spindle; attached to the ends of this bar were

stout sash cords which were brought past the head stock and then joined. A spreader was inserted between the cords so that they touched no part of the machine.

Where the cords were brought together, a spring balance was hooked on. Attached to the other end of this balance was a cord leading down over a pulley; to the end of this cord weights were fastened, until the desired pull was registered on the dynamometer. The friction of the spindle was practically nothing, so that the pressure on the drill could be read directly at any time.

FIG. 98.

The recording mechanism I think explains itself. The motion of the drill was multiplied five times. The board *A* carrying the card was moved across the latter by means of a positively geared cross feed, at the rate of 1 inch per hundred revolutions of the latter spindle. *C* was fastened to *B* by a screw, as shown, and *B* was clamped to the lathe apron.

The results obtained were practically the same as Mr. Keep's, although the pressure was only 80 pounds, and the angles were much greater in consequence.

To carry out the original argument, that it is the outside of the casting which is machined, and therefore the part to be tested, the drill on *entering* the casting draws a curve whose angle of direction starts at 0 degrees and gradually increases, but increases *beyond* the angle made by the drill when it has penetrated $\frac{1}{8}$-inch or so under the surface. This is shown in Fig. 99 where the dotted line *A B*

shows that the "angle of penetration" of the drill was influenced by the denser layer of metal through which *part* of the edge of the drill was cutting at that time.

Mr. Keep does not mention the work done along this line by Professor Chamberlain, who at the meeting a year ago described his "Dynamograph." In this machine it is the part of the casting near the surface which is tested.

Practically the same operations are performed in testing as in

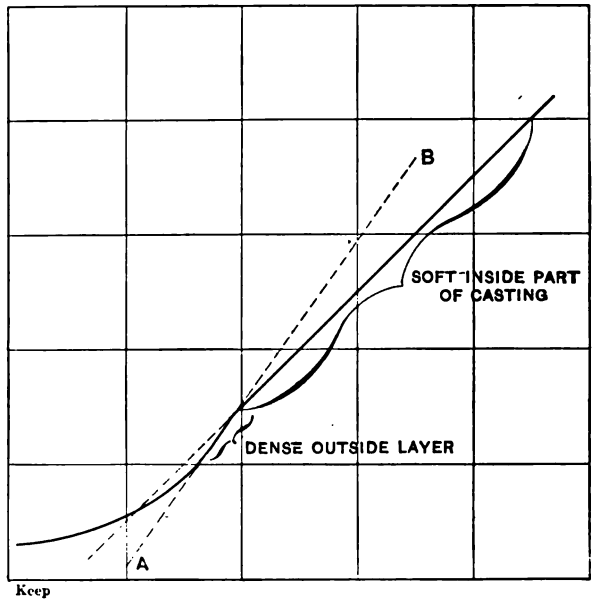


FIG. 99.

actually machining a casting. The outside of a test piece is turned off in a specially constructed lathe, which makes an autographic diagram of the power required to make the cut. One cut is taken which cuts through the scale, and reduces the piece to a certain size, when a second cut is made. These cuts remove about the same depth of metal that would be machined off a casting in finishing.

Mr. Thomas D. West.—The closing of Mr. Keep's paper on "Hardness of Metals" would lead some to believe that a hardness test of pig iron can be used to define what grades of castings pig iron will produce. If Mr. Keep's proposition were practical, the analyzing of pig iron, now practised by nearly one-half of our foundries, would never have been inaugurated. For over a century,

founders have been guided by the fracture of pig iron, which is generally no more or less than being guided by hardness. There are two ways of producing degrees of hardness in pig iron or castings. One is by varying the percentages of silicon, sulphur, manganese, and phosphorus in iron; the other, by varying the rate of solidification and cooling to a cold state. Alterations in any of these can cause the carbon to take combined or graphic forms. The more combined the carbon the harder the iron, and the more graphite the softer it is. To demonstrate the impracticability of hardness tests for pig iron as it is now manufactured, I am

FIG. 100.

sending two samples, Nos. 1 and 2, which, if tested for hardness would be found to be so different that anyone being guided by hardness tests would say that No. 1 would make a very soft casting, while No. 2 would make a hard one; when, in fact, each will give like softness in castings of like thickness and treatment in cooling. It does not require a delicately arranged device to discover the difference in the hardness of these samples, as anyone who will drill them with a common drill will find one sample a great deal harder than the other. In drilling these samples with a drill press running at a uniform speed or pressure, it took eight minutes to drill No. 1, and twenty-two minutes to drill No. 2, a difference of fourteen minutes. A $\frac{1}{2}$-inch twist drill was used,

and the method of drilling will be seen by the half holes seen on the back of the specimens, or seen in No. 3 of Fig. 100. The difference in the hardness of these samples, it is to remembered, is found in samples of like analysis coming from the same tap, and cast in sand moulds. That No. 1 and No. 2 are of the same cast and analysis can be verified by any who will take drillings of the samples and analyze them; excepting the state of the carbon, they will be found practically alike. Then, again, if any desire to test the hardness by drilling, he can take the samples on exhibition, or I could send them others.

All those who, like the writer, are placed in a position to observe almost daily the workings of different furnaces, should they desire, know that there is no furnaceman living who can now guarantee a furnace never to vary in its workings. As long as this cannot be achieved, we may expect that the hardness of pig iron will always vary, and may not be in accordance with the grade results that a chemical analysis would show, thus proving the test for hardness impractical, as fully demonstrated by such samples as Nos. 1 and 2.

Prof. W. T. Magruder.—As a test of workability of metals, the Bauer method, as modified by Mr. Keep, promises to satisfy the requirements of the average commercial shop or foundry, when the various details have been completely worked out experimentally. To do this, friction must be reduced to a minimum which should be constant, and the sliding parts should be effectively protected from chips and dust from the drill. Not only must the drills be of uniform size and shape and temper, but they must be ground exactly alike and kept so, as otherwise we may expect angles of 77, 59, 30 and 25 degrees with a straight drill (as given on page 5 in fourth paragraph). While comparisons may be obtained of the drillability of different metals with uniform pressure and at uniform speeds, and using one drill, the question arises whether this is a fair test. Is not the feeding pressure exerted a very important factor in the test for workability? Given a hard cast-iron and a comparatively light pressure, instead of cutting, the drill will scrape; and it will take hundreds of revolutions to advance the drill the desired amount. With an increase of pressure on the drill, it will begin to cut, and may even autographically describe the same line that was obtained from a piece of soft cast-iron with lighter pressure. On the other hand, the same maximum load might not answer for brass. I would

suggest that the effect of change of pressure on the drill for different metals be studied.

I cannot agree with the author that "gray cast iron suitable for machinery castings is usually uniform in hardness throughout a test bar." Experiments on bars of different mixtures and tested by the Bauer method confirm experimental results obtained by a different method at the Ohio State University and showing that bars of cast iron 2 inches by 2 inches by 12 inches cast on end are generally harder at the bottom, and sometimes as much as $\frac{5}{16}$ per cent. harder.

*Mr. W. J. Keep.**—The diagram of the first $\frac{1}{16}$ of an inch of the test bar is $\frac{5}{16}$ of an inch long, which will give the hardness angle accurately. Either the engraver has distorted his diagram, or the sharp changes are caused by his temporary apparatus; for the reason that in ordinary gray cast iron there can be no sudden change in hardness. If there is any change, it is very gradual and slight. I measured the same part of each diagram to make records comparable.

Mr. West says that "Founders have been guided by the fracture of pig iron, which is generally neither more nor less than being guided by hardness." "No furnaceman can guarantee the uniform working of a furnace, and the hardness will always vary, and may not be in accordance with the grade results that a chemical analysis would show." He presents two samples of pig No. 1 three times as hard as No. 2, and yet says they are "of like analysis excepting carbons." "The more combined carbon the harder the iron," but he says that the pigs made castings of the same hardness. If, as he says, the silicon, phosphorus, sulphur, and manganese are alike in each pig, and that hardness varies as these vary, then the silicon in these pigs, as found by analysis, did not indicate the combined carbon or hardness of the pig or of the casting. If the analyses of these pigs were the same, and if he ever made a casting from either, would not he have published the analysis, and have told how long it took to drill each casting? Did he not get his samples mixed, and is not No. 3 the back of No. 2 instead of No. 1?

I believe in having all the chemical analysis that we can afford. My contention is, that because the physical properties of cast iron do not always follow changes in chemical composition, that the only way to find the result of such variation is by physical tests.

* Author's closure, under the Rules.

No. 879.*

A NEW PRINCIPLE IN GAS-ENGINE DESIGN.

BY C. E. SARGENT, CHICAGO, ILL.
(Member of the Society.)

WHILE the gas engine has become such an important prime mover that it is looked upon and is, to-day, a most formidable rival of the steam engine, it has certain disadvantages as a power generater which are not only recognized by its devotees and manufacturers, but are considered inherent and beyond elimination by many of those who have given the internal combustion engine a great amount of study. To overcome these disadvantages, eradicate the defects, improve the efficiency, and design an engine which would meet the requirements of prime movers, and one which would not only be simple and cheap to construct, but one which could be easily manipulated and controlled by the average engineer, has been the object of the author, and the result the subject of this paper.

In order to understand thoroughly the disadvantages of modern gas engines, it is necessary to consider the cycle and operation of the working parts. As it is not in our province to criticise what is recognized as being the best warranted by the state of the art, we will refer only in general to the shortcomings of the modern gas engine of the four-cycle type, by which is meant an engine with one or more cylinders fitted with trunk pistons, working on the Beau de Rochas or Otto cycle, in which the piston acts during the first, or forward, stroke (towards the crank) as a pump, drawing in the charge of air or of a combustible mixture; compressing same on the second, or back, stroke completing the first revolution of the crank shaft; performing work during inflammation, the forward stroke of the second revolution, and exhausting the burnt products during the back stroke of the second revolution. Such is the operation of the

* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

modern gas engine, with a few possible exceptions which will not be considered herein. Engines working in this way have been in successful operation twenty years; yet that there is large room for improvement no one denies, but, on the contrary, authorities on the subject say that the mechanical and thermal results are very inefficient, and anticipate improvements which will improve the mechanical as well as the thermal efficiency.

In specifying the disadvantages of a single-cylinder gas engine, we find that, on account of but one impulse being obtained for every two revolutions of the crank shaft, the working parts must be sufficiently heavy and strong for the three idle strokes as for the impulse stroke; therefore, the engine is practically four times as heavy per horse-power as it would be if the impulse were received every stroke of the piston. No compression is possible on the forward stroke, and, as compression takes place every other revolution only on the back stroke, a heavy frame and foundation are necessary to prevent injurious vibration. In order to absorb the inertia of the reciprocating parts and to improve the regulation, some manufacturers put two, three, or even four cylinders side by side, thus getting as many impulses in the cycle of two revolutions as there are cylinders, and, by transmitting the strains through the crank shaft, as many compressions as there are impulses. An engine working under these conditions may run very smoothly, be in running balance, and give excellent results from a mechanical standpoint. With a single-cylinder, single-acting engine, to get regulation equal to an engine getting an impulse every stroke, it is necessary to have a flywheel of four times the capacity.

Governing.

When a single-cylinder engine is governed by missing an explosion, an impulse may be obtained in every fourth or sixth revolution, and, on account of the burnt products having been cleared out, when the engine does take an explosive charge, the first impulse, after skipping a charge, is very severe, giving a much higher initial pressure than the ordinary impulse, which, though it may be conducive to economy of gas, is not conducive to the longevity of the engine. With a "hit-and-miss" governor there is greater economy, because the compression is

practically uniform; but with this kind of governing the engine is constantly racing, and, though it may be adjusted to vary not over 2 per cent. in revolutions between full and no load, its angular velocity is always increasing or decreasing, as a look through a vibrating tachometer at the flywheel of this kind of an engine will impress you. A better method of governing is by varying the mean effective pressure by throttling the fresh charge. A regulation sufficiently close for electric lighting, even with a single-cylinder engine having sufficient flywheel capacity, may be obtained in this way, but at the expense of thermal efficiency. This is best illustrated from an indicator diagram of a light load represented in Fig. 101, and taken from a paper presented to the Society one year ago. The engine was rated at 125 horse-power, and the diagram was taken when the engine had about one-quarter load. *Ab* is the atmospheric line,

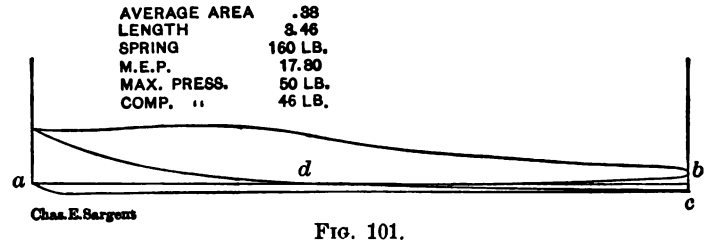


FIG. 101.

and *ac* the admission line. The mixture is throttled by the governor, and, as the admission line is about five pounds below atmospheric pressure, there is a loss by wire-drawing represented by the area *acda*. On account of the throttling of the admission there is only about one-half a cylinder volume of combustible mixture; consequently, the compression is only one-half what it should be for economy, and what it is at full load, as shown in diagram (Fig. 102) taken from the same engine.

The thermal efficiency of the engine when developing the load represented by diagram (Fig. 102), is nearly twice that when developing the load shown in Fig. 101; yet the temperature and pressure of release at the end of working stroke of the full load are considerably more than at one-quarter load. As the efficiency should increase as the terminal pressure and temperature are lowered, throttling the admission and lowering the compression and its attendant results must cause a considerable loss. As

the load decreases, the quantity of combustible mixture is decreased; but as the clearance remains the same, the mixture is weaker, inflammation is slower, and as ignition takes place at the same point, the piston runs away from the explosion (see Fig. 101), making the highest pressure and temperature where the proportion of cooling surface is greater, which accounts for the rapid falling of efficiency pointed out in previous paragraph.

The high pressure and temperature when the exhaust opens at full load are the sources of greatest loss in an internal combustion engine. In the paper from which the diagrams were taken, it was stated that fifty-seven per cent. of the heat units pass into the exhaust, the pressure of which, at the moment of opening, is forty to fifty pounds absolute, and the temperature from

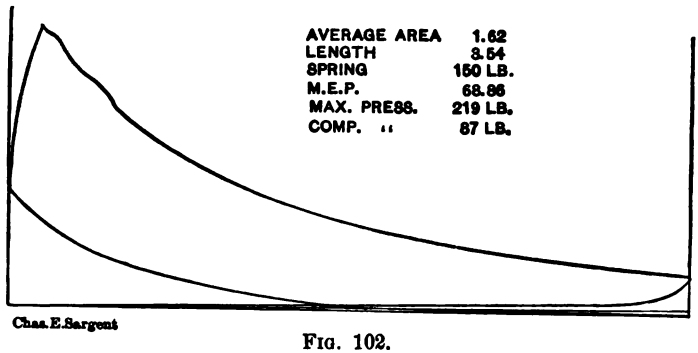


FIG. 102.

1,100 to 1,200 degrees Fahr. This terminal pressure is so great that in large engines it often requires a lifting force of more than a ton to open the exhaust valve, and though the actual horsepower used is a very small per cent., the strain on the gears and shafting is worth eliminating.

With a terminal pressure of forty to fifty pounds absolute, mufflers to deaden the "bark" are absolutely necessary, and with a release at 1,200 degrees Fahr., and an initial temperature of probably 2,700 degrees Fahr., the average temperature of a cylinder must be near the critical point, where, with high compression, back firing and premature ignition are liable to take place, the cooling effect of the jacket water to the contrary notwithstanding. This is one of the most aggravating things in an internal combustion engine, and any change in design which would overcome this trouble would be of inestimable value.

Starting.

As all gas engines which are sufficiently economical for practical purposes must compress the combustible charge before ignition, and consequently before any work is given out or stored in the flywheels, the starting of the internal combustion engine has been one of the greatest troubles to overcome. It is accomplished in small sizes by man-power storing up energy in the flywheels, or by compressing the entire charge with a windlass; while in larger sizes, compressed air, with its necessary reservoirs, pipes, and pumps, is used. Many start the engine with a charge of gunpowder or combustible mixture of gas and air, giving, from a standing position, such a shot that the inertia stored up will compress the next charge and keep the engine going. Nearly every manufacturer has a perfect starter, yet, where compression must take place before ignition, the difficulties encountered in always getting an engine to go are evident. Such are some of the thermal and mechanical disadvantages of the modern gas engine.

Ideal Method.

In accounting for the heat in the internal combustion engine, we have:

First, Heat converted into work;

Second, Heat imparted to water jacket;

Third, Heat released in exhaust.

As the sum of the three is constant in order to make the first as large as possible, it is necessary to reduce the second and third. As the cylinder walls must be sufficiently cool for proper lubrication, we cannot expect to reduce this loss materially, yet by improving the conditions the best possible efficiency may be obtained. The transmission of heat from the burning charge to the cylinder walls depends, for one thing, on the ratio of surface exposed to the unit of volume. The reason that compression is necessary for high efficiency, and that the efficiency increases with compression is, that while the volume remains constant, the cooling surface for radiation diminishes. It is impossible to get any more heat out of the gas than there is in it, and with complete combustion there is just as much heat released in a non-compression engine of the Lenoir type as in the Diesel motor, and the only reason why the latter shows such excellent

efficiency is because the compression is so high that the surface of radiation during inflammation is comparatively small. Time is another factor in the transmission of heat from the burning charge. If the engine is put on centre, so that it cannot be moved, and no heat can be turned into work, and the charge exploded in the compression chamber, the pressure should fall to the same pressure it had before ignition took place, in about one and one-half seconds, which shows that high-piston speed is essential in a gas engine, as well as in the steam engine, for economy. The quicker we can expand the burning gas, the less heat will go into the jacket and more into work.

The transmission of heat from the burning charge to the water jacket depends also upon the difference between the mean temperature of the gases during the working stroke and that of the cylinder walls, so that the lower the terminal temperature, other things being equal, the lower the mean temperature and less heat will be lost. We see, then, that the loss of heat to the water jacket depends on the ratio of the volume of explosive mixture to the surface which confines it, to the piston speed, and to the average temperature of the burning gases, none of which has been neglected in the designs presented. The prime object in bringing out a new design of gas engines was to get a more complete expansion of the gases during the working stroke. It is evident that if a cylinder full of combustible mixture is compressed, ignited, and allowed to expand to its original volume (a cylinder full) and then released, the terminal pressure and temperature will be considerably higher than when compression began, while if this expansion could continue until the pressure and temperature were the same as before compression, the only loss would be the amount of heat absorbed by the water jacket. In Fig. 103, *chicbfe* is the theoretical perfect diagram of an internal combustion engine igniting the charge at constant volume, taken from the latest edition of Clerk's "Gas and Oil Engine," p. 50, which shows an expansion of the gases to the atmospheric pressure. Mr. Clerk, as well as all other authorities on internal combustion engines, says, however, that such a complete expansion has never been obtained. The desirability of attaining such results, however, is emphasized by all writers when discussing the possibilities necessary for an increased efficiency, and though the realization of such results in a single-cylinder engine is not considered, the probability of securing a better

expansion of the gases by compounding is suggested, and has been tried with more or less success. Looking once more to Fig. 103, we see that if the original volume of combustible mixture, including the clearance, were taken as a unity, an expansion to two and seven-tenths ($2\frac{7}{10}$) volumes would bring the pressure to atmospheric. While the writer has obtained as great an expansion as that indicated in Fig. 103, the work produced is so small during the last part of the stroke, and an engine so large for the power developed, that no attempt has been made in practice

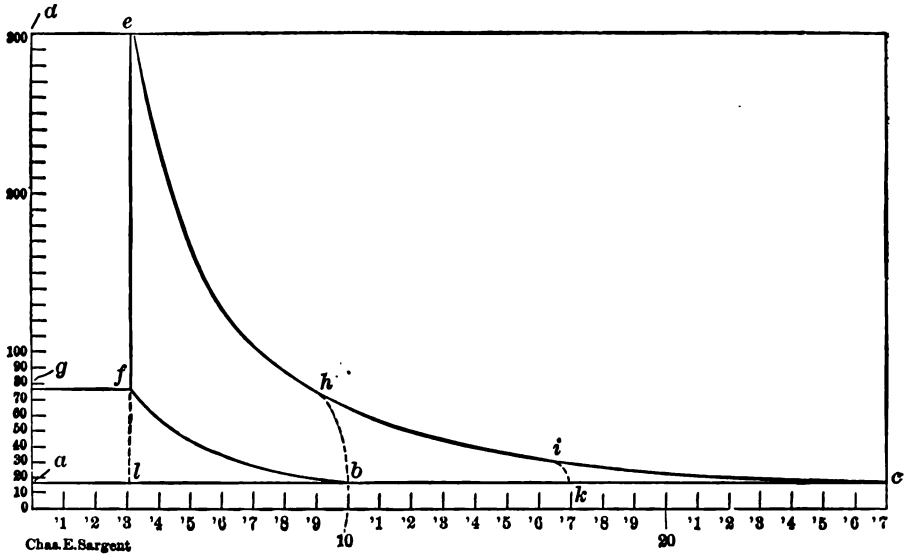


FIG. 103.

to get, at full load, a lower terminal pressure than eighteen to twenty pounds absolute.

Referring to Fig. 103, if *lb* represents the length of piston stroke then *fehbf* would be the theoretical power diagram such as is obtained from the modern gas engine, wherein expansion beyond original volume does not take place. If, instead of releasing the burning charge at *h*, we could expand to twice the volume of piston displacement and release at *i*, there would be added to our power diagram area *hikbh*, and much of the heat ordinarily lost in the exhaust would be turned into work.

Now, to build an engine which would give a diagram *feikf*, all that is necessary is to cut off the fresh charge at *b*, allow it to rarefy and return to atmospheric pressure at *b*, as the piston

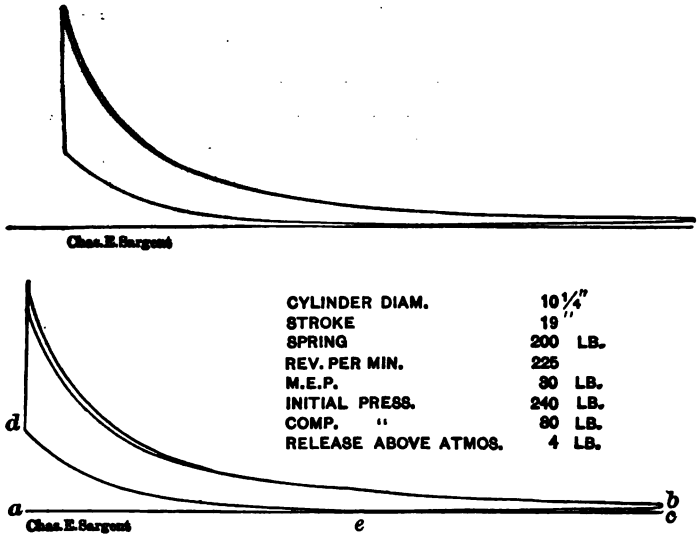


FIG. 104.

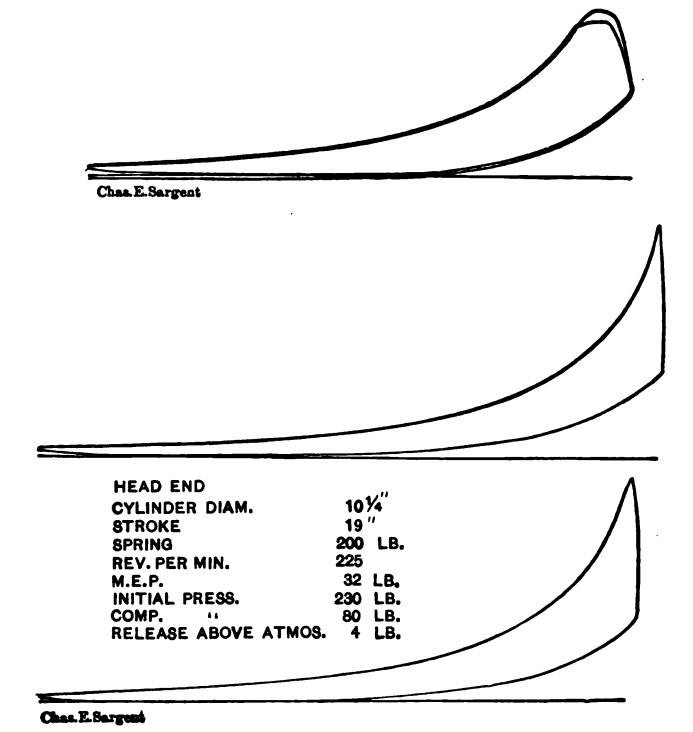


FIG. 105.

returns, compress to *f*, ignite and expand from *e* to *i*, the end of the forward stroke where exhaust opens and the products are driven out as the piston travels from *k* to *l*, the end of the back stroke, when the operation is completed.

Figs. 104 and 105 are diagrams taken from an engine hereafter described, working in this way, which approach very closely the

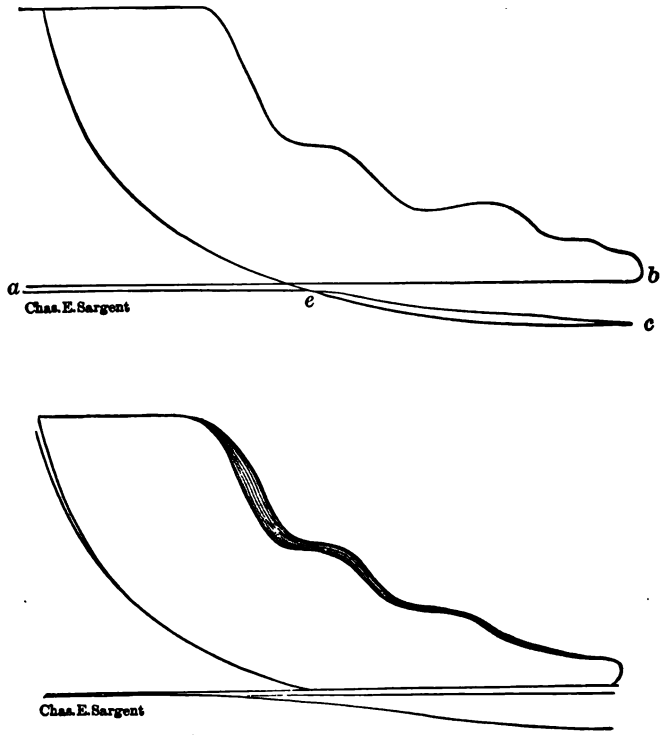


FIG. 106.

ideal card, and Fig. 106 is a diagram taken at the same time with a light spring fitted with a stop.

Referring to Fig. 106, *ab* is the atmospheric line and length of stroke; when the piston travels from *a* to *b*, the charge is admitted to *e*; when the admission is cut off, the pressure drops to *c*, the end of the stroke, and returns to *e*, as the piston returns where compression above atmosphere begins and continues to *d* (Fig. 104), when ignition and expansion take place, and the exhaust opens at the end of the stroke *b*, slightly above the pressure of the atmosphere. There is no loss in rarefying the fresh charge

from *e* to *c*, as the work is given back to the piston as it returns to *c*, and the compression above atmosphere takes place during the last half of the compression stroke. If the full power of the engine is obtained, say, at one-half cut-off, and it is so designed that the highest compression permissible takes place when giving its full rated power, then by making the governor cut off the admission and ignite earlier as the speed increases, we ought to obtain a much higher efficiency for light loads than is usually

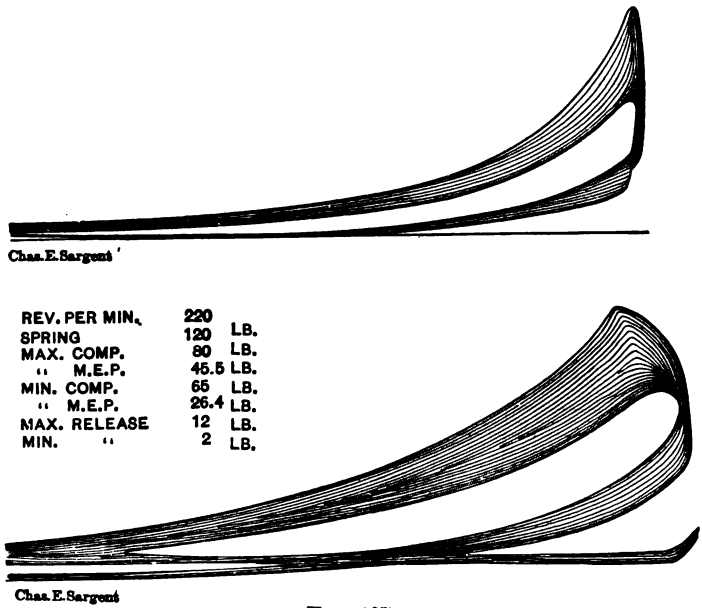


FIG. 107.

obtained by throttling the charge, as there is no loss by wire-drawing or by late ignition, as heretofore pointed out.

Fig. 110 is a diagram taken from both ends of one cylinder while developing a constant load.

Fig. 107 is a diagram taken with a 120-pound spring from the engine during a change of load of about five seconds' duration, and Fig. 108 is a diagram during four working strokes, which shows the action of the governor in cutting off the admission earlier, and thereby varying the mean effective pressure; yet, by the simultaneous advance of the igniter, the initial pressure is always greatest at the beginning of the stroke. No loss from wire-drawing is perceptible, and the terminal pressure approaches

very closely to the atmospheric line. The only possible chance for a drop in thermal efficiency with a light load is that loss caused by a lower compression, which is probably balanced by the lower pressure and temperature of release, for the efficiency depends on the difference between the initial and final temperature, and, as the construction of the engine is such that the compression falls only one-half as fast as the cut-off recedes, the thermal efficiency should be nearly constant throughout a considerable range of load. With such a cycle, let us see what is gained. With a full load, a diagram shows from twenty to twenty-five per cent. more area than is usually obtained from modern gas engines; consequently, twenty to twenty-five per cent.

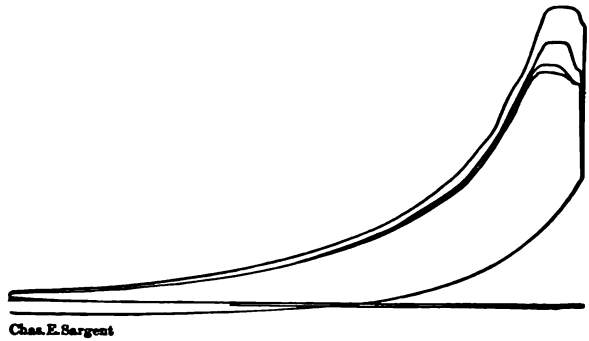
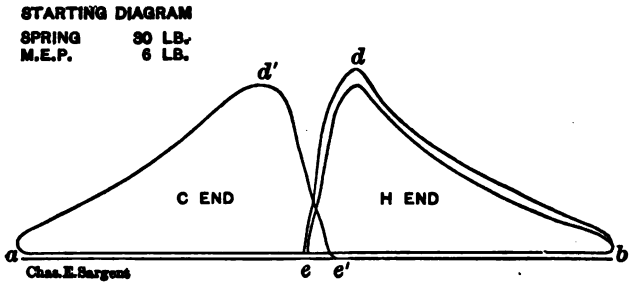


FIG. 108.

more heat is turned into work for the same amount of fuel. A noiseless exhaust, doing away with mufflers, is possible. The average temperature of the cylinder is reduced several hundred degrees, avoiding the probability of premature ignition. The pressure on the exhaust valve is removed, taking a great strain from the side shaft, and on account of lowering the average temperature, makes possible the use of a piston rod, and a double-acting tandem engine; therefore, an impulse can be obtained at every stroke, as well as a compression for every impulse to absorb the inertia of the moving parts without transmitting any strain through the crank shaft. One crank pin may do four times the work of the crank pin in the ordinary gas engine. The desirability of using two tandem cylinders and getting an impulse at every stroke has long been recognized, and tried with more or less success. With a temperature of 1,000 degrees Fahr. or more for the release, it is no wonder that hollow piston

rods, with the water running through them, must be used. The catalogue of one prominent manufacturer of gas engines says: "Single-acting cylinders and trunk pistons are used because they are absolutely necessary in a gas engine, for the reason that stuffing boxes and piston rods deteriorate too rapidly in such a temperature," which would, no doubt, be true of the engine described in this catalogue, as the temperature of release is from 1,000 degrees to 1,200 degrees Fahr., maintaining, neces-



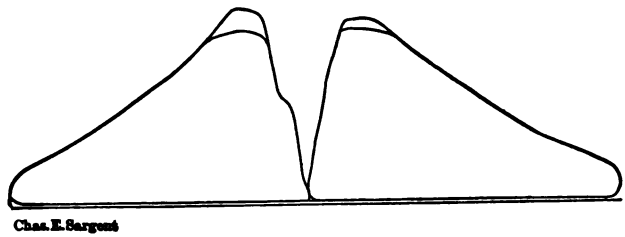


FIG. 109.

sarily, a red-hot exhaust pipe. But, with the comparatively low temperature secured by more complete expansion, a piston rod running through water-jacketed stuffing boxes has worked satisfactorily.

With a variable load, no loss by wire-drawing of the incoming charge is possible; the mean effective pressure drops much faster than the compression, and the highest pressure and temperature take place where the radiating surface is the least. A regulation equal to the best steam engine is possible and,

with a practically uniform compression, smooth running is the result.

While a more complete expansion of the gases is the essential feature of this paper, the adoption of such a cycle not only permits the construction of an engine having an impulse every stroke, but suggests a method of starting an internal combustion engine which has more than fulfilled our anticipations.

Referring to Fig. 106, if the valve mechanism were so arranged that ignition took place at the point of admission closure or cut-off (*e*), and the exhaust would open at the end of the stroke and remain open during the back stroke of the piston, and repeat the same cycle each crank shaft revolution, we would get an impulse every stroke, and with but one double-acting

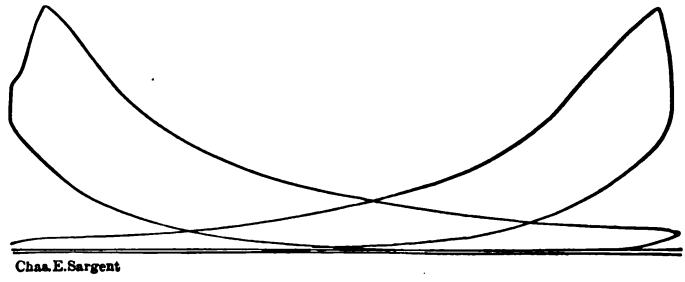


FIG. 110.

cylinder, would get two impulses every revolution of the crank shaft.

By the simple moving of a lever (hereafter described) the engine may be changed from the ordinary four-cycle to this non-compression cycle, and Fig. 109 is a diagram taken from the engine after starting same by turning the flywheel one-quarter of a revolution. The operation is as follows: The charge is drawn in by turning the engine by hand; as soon as the piston which starts at *a* reaches *e*, cut-off takes place, and ignition fires the charge, while the pressure goes up to *d* and expands to the end of the stroke *b*, where exhaust opens; the other end of the cylinder performing the same operation produces the diagram *be'd'ab*. As soon as the engine is up to speed, the ordinary cycle is thrown into operation.

The cycle of this engine when starting will be recognized, by those familiar with the history of internal combination

engines, as that of the first successful gas engine invented by Lenoir.

Such are some of the advantages of the engine which will now be described, and though the details may have to be modified as long-continued operation will develop the defects, the author feels that the principles evolved are a great advance in internal combustion engine design, and that the method of accomplishing the results obtained will be of interest to the Society.

Description of Engine.

Fig. 111 is a half-tone of the plain pulley side of an unpainted 50 horse-power engine, and Fig. 112 is a half-tone of the governor pulley side of the same engine. Fig. 113 is a side elevation of the plain pulley side, and Fig. 114 is a side elevation of governor side of the same engine, showing the governor, side shaft, starting lever, valve cams, and igniters. Fig. 115 shows a vertical section lengthwise through the centre of a 75 horse-power engine, and Fig. 116 a vertical cross section through the crank end valve of the head end cylinder of the same engine, looking towards the crank shaft, and Fig. 117 a vertical cross section through the crank shaft, looking towards the cylinder. In general it is a horizontal centre crank, self-contained engine, the main frame of which rests on a sub-base (which could be replaced by masonry if desired) sufficiently high for the wheels to clear the floor line. The frame is of the self-oiling enclosed type, keeping the oil in and the dust out, with bored guides and side doors giving access to cross head and stuffing box. The cylinders are made with one head cast in and a valve chest on the bottom of each end. The crank end cylinder is centred in and bolted to the frame. To the head of this cylinder is bolted the distance piece which makes a cylinder head, and to which is centred and bolted the head-end cylinder. A pedestal under the distance head to the sub-base, or foundation, prevents the cylinders from sagging, yet allows linear expansion so necessary in a heat engine. The air for each cylinder is taken from outside of the engine room or from the perforated extension of the sub-base (Figs. 114 and 116), which deadens the noise of suction while the exhausts from the cylinders are connected together (Figs. 113 and 115), and run where desired. No muffler or exhaust head is used. Each cylinder is water jacketed, and the water

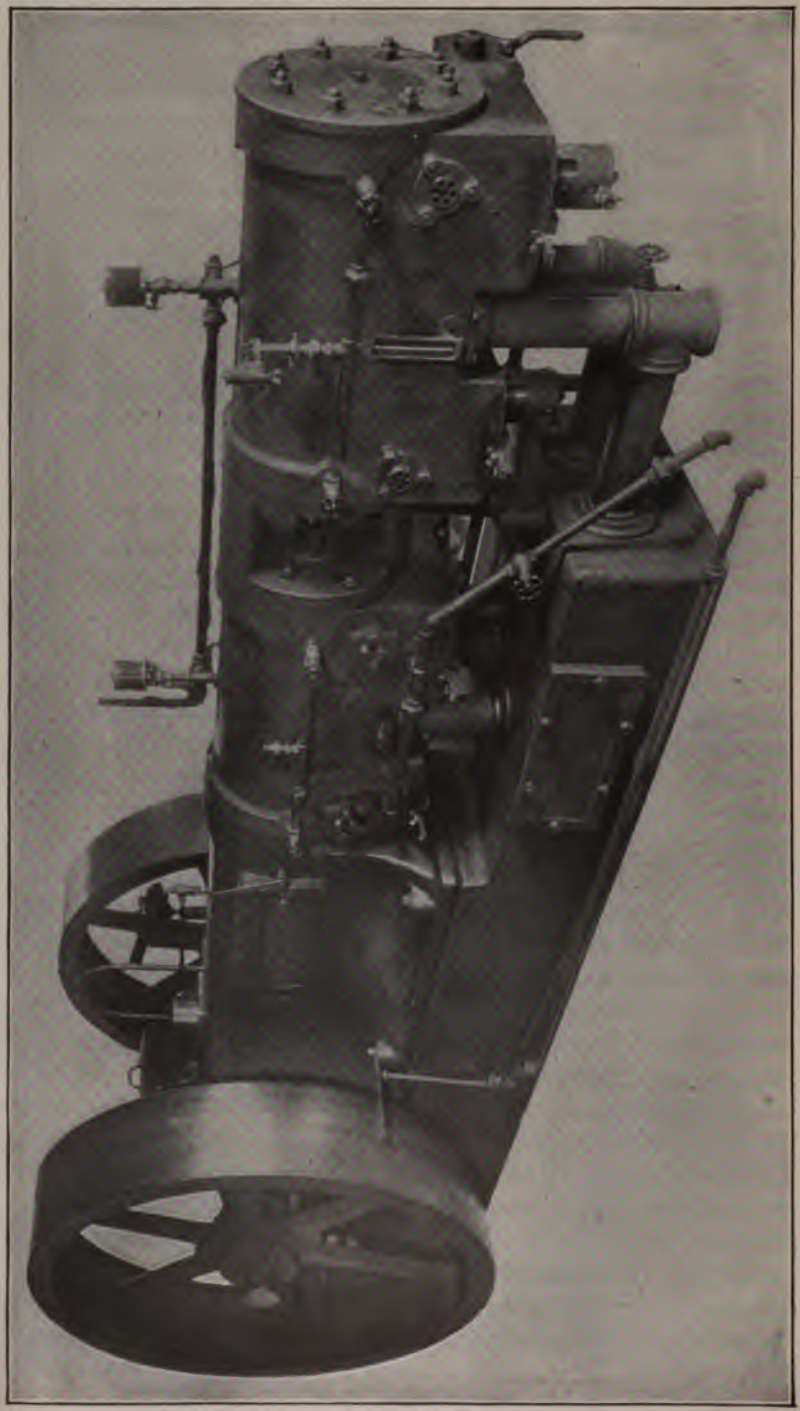


FIG. 111.

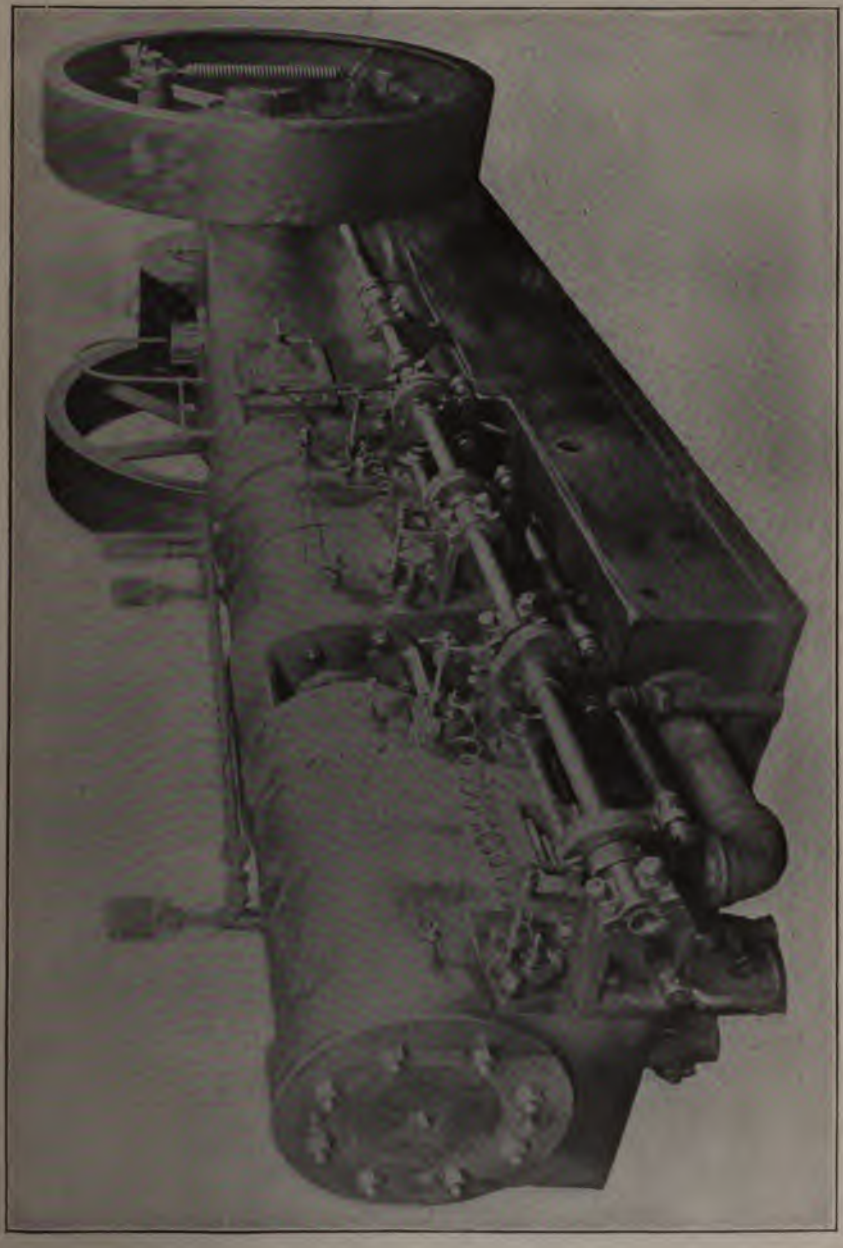


FIG. 112.

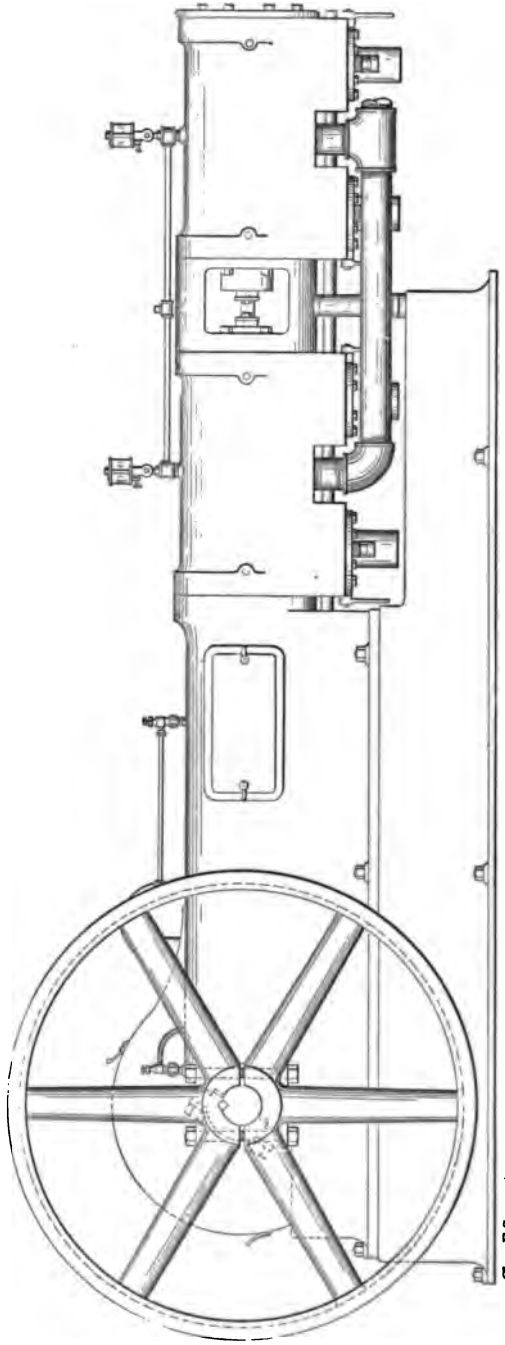


FIG. 113.

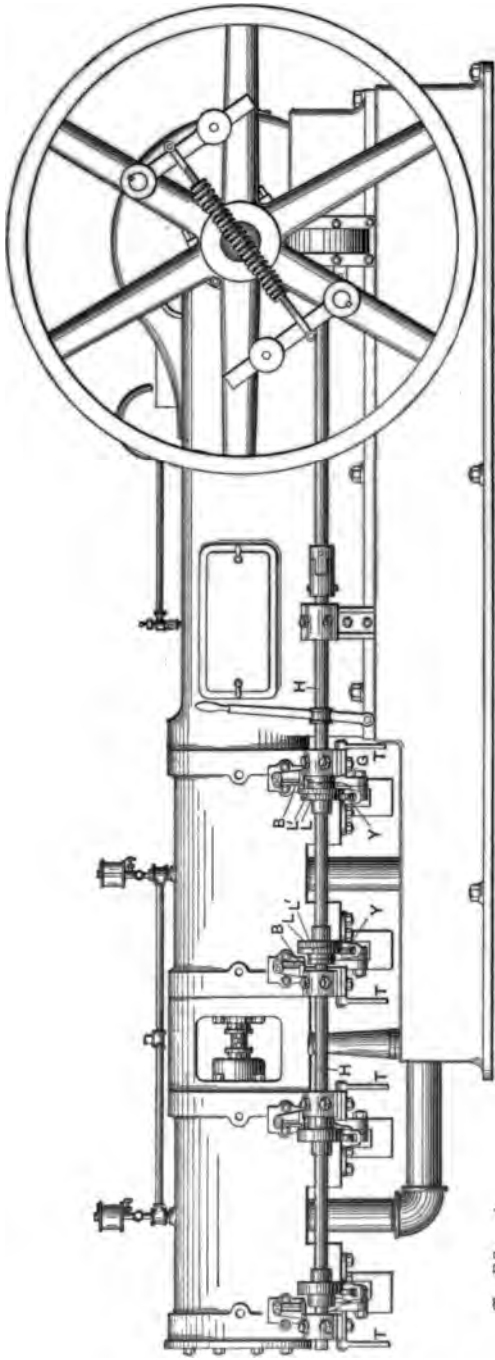


FIG. 114.

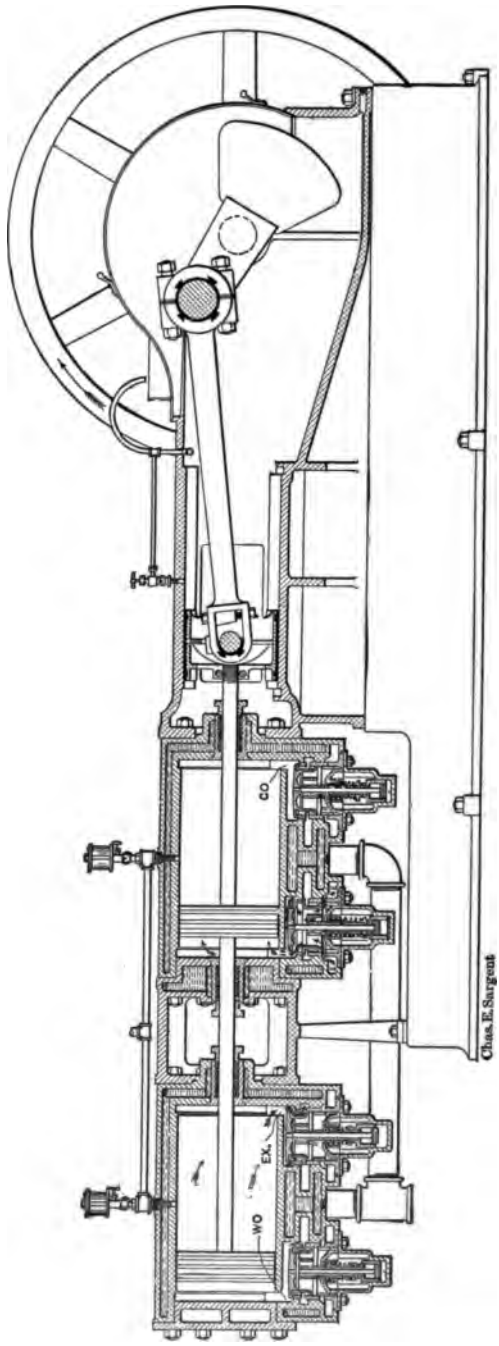


Fig. 115.

surrounds each piston-rod stuffing box and valve chest. Water enters at the bottom centre of each cylinder and passes out the centre and top through the same opening in outer shell as the cylinder oil passes in, as shown in Fig. 115. Provision is made for a thermometer at the water outlet of cylinders, and in the exhaust gases before leaving the cylinder, as shown in half-

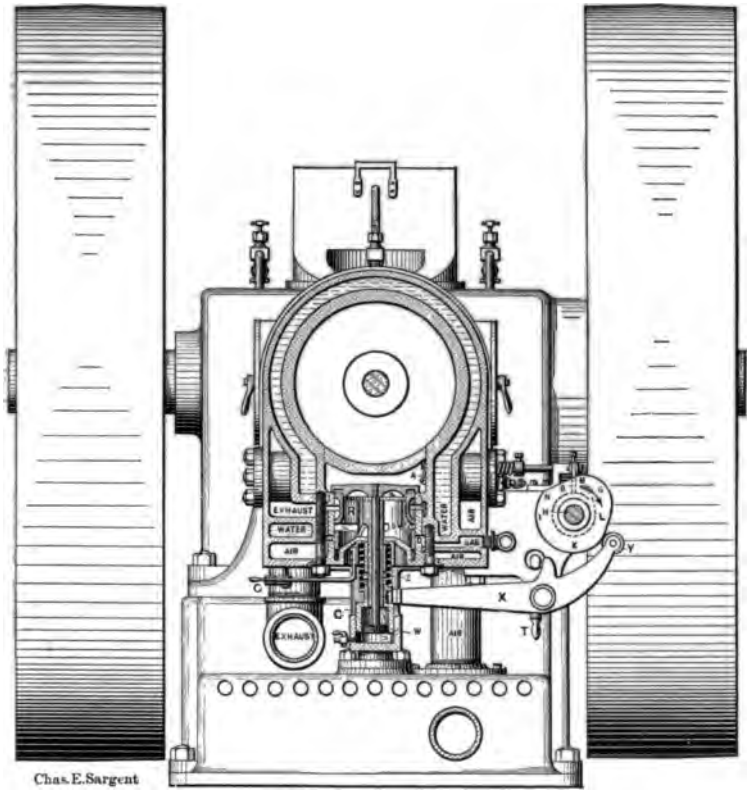


FIG. 116.

tones. Each combustion chamber (clearance space) has one port in the bottom, both for admission and exhaust (Fig. 115), and one vertical poppet check valve, which is held to its seat during compression and inflammation by the internal pressure. There is also a vertical piston valve *R* in each valve chest (Figs. 115 and 116), which opens and closes the exhaust ports and air and gas ports at the proper time.

The side shaft *H* (Fig. 114, and in section Fig. 116) is driven by

worm gears of the same diameter (Fig. 117) at one-half the speed of crank shaft, as in ordinary four-cycle engines. The valve cams and igniters, one for each explosion chamber, are keyed to this shaft 90 degrees apart, so that one end of one cylinder is always giving an impulse stroke, while the three other ends are exhausting, compressing, or drawing in a fresh charge respec-

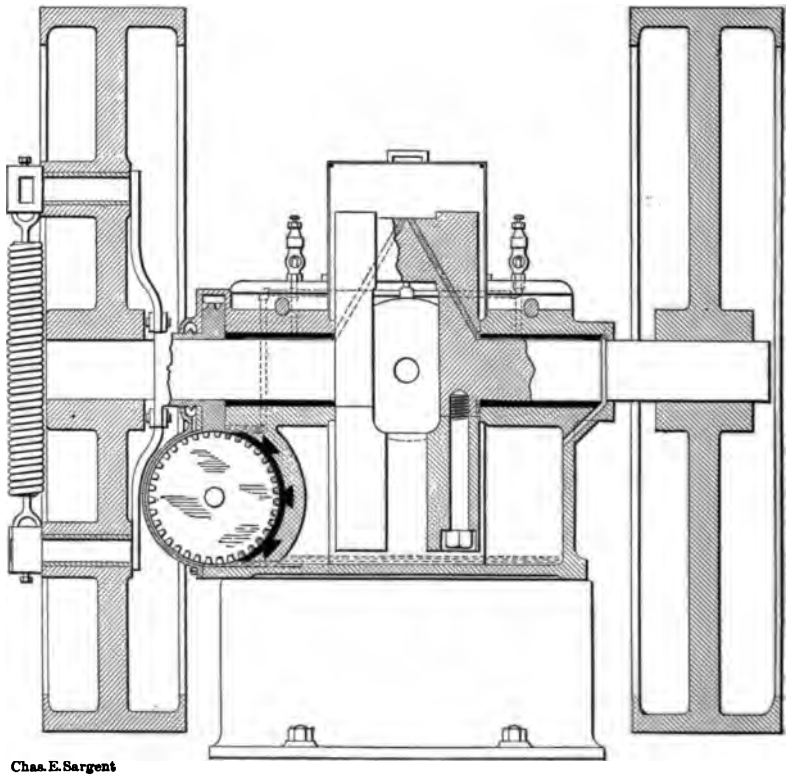


FIG. 117.

tively. As all valve chests and connections are duplicates, a description of the operation of one will suffice. In Fig. 116, *X* is a lever, one end of which is forked around collar nuts screwed to the stem of the piston valve *R*, by which this valve is controlled; *Y* the roller, carried by the other end of lever, which is held against the cam *MK* by the spiral spring *Z*. As the piston in the cylinder makes four strokes every time the cam *MK* makes one rotation, this cam must perform all operations while going once around. That part of the cam *NIKL* being a circle,

causes no action of the piston valve and is called the normal part of the cam. When the point *I* is in contact with the roller *Y*, the piston is at the end of the suction stroke, or at *b* (Figs. 104 and 106). When the part *IK* passes the roller *Y*, one-quarter of the cam shaft rotation, the piston has moved through one stroke and is at *a* (Fig. 104), while the compression has gone up to *d*. When *K* is at the roller *Y*, the cam *G* has just passed under the igniter rod *B*, causing a contact and break between the electrodes at *A*, igniting the charge, and, by the time *L* reaches the roller, the piston has made the working stroke, and here that part of the cam *LM* pusnes the roller end of the lever down while the other end goes up, carrying the piston and poppet valve until it is in the position shown at *Ex* (Fig. 115) for one stroke, during which exhaust takes place. When the piston is at the end of the exhaust stroke, and *M* is at *Y*, the cam has allowed the roller to return to its normal position, as shown in Fig. 116, and at *Co*, where compression is taking place, and *Wo*, the working stroke (Fig. 115), closing the exhaust port and allowing the poppet to seat; but as the depressed part of the cam *MN* passes the roller, the spring *Z* drives the roller up into the depression, while the piston valve goes down until the air and gas ports register as at *In* (Fig. 115), when gas and air, in the right proportion, are drawn in. To the lower end of the poppet valve stem which passes through the piston-valve stem, is attached a small piston *W* (Fig. 116), working in the cylinder *V* of a dashpot piston *C*, which moves with the piston valve. Now, as the piston valve descends by the action of the spring *Z* from the position of exhaust shown at *Ex* (Fig. 115) to the position of induction *In*, the air in *U* being compressed by the downward movement of the dashpot *C* forces up *W*, raising the poppet valve *P* again, which is seated for an instant when the piston valve passed its normal position, passing from exhaust to admission, thus holding open the poppet valve as shown at *In*, while air and gas are admitted to the cylinder. When the piston has made one-half a stroke, or arrived at *e* (Fig. 104), the part of the cam *N* reaches the roller, depresses it, and raises the piston valve to its normal position, as shown in Fig. 116, cutting off both gas and air, and allowing rarefaction to take place from *e* to *c* (Fig. 104), when the cycle is repeated. After cut-off takes place, the poppet may remain open until the return stroke begins, to allow the mixture in the valve chest and cylinder to have equal

tension; but from cut-off to exhaust opening, one and one-quarter rotations of the crank shaft, the piston valve remains in its normal position, closing both inlet and exhaust ports. The gas port *D*, and air port *E* (Fig. 116), are separated by a web (see also Fig. 118, which is a horizontal section through air and gas ports), so that when the piston valve is in its normal position, and these ports through the bushing are covered, gas is shut off from the air. When induction takes place, the port *F* in the piston valve registers with the air port *E* (see position of valves at cylinder port *In*, Fig. 115) and the gas port *D*, shown only in Fig. 116. The port *F* does not run entirely around the piston valve, but is left solid at *S* (Figs. 116 and 118), which is just the right width to cover the entire gas port, if desired, when the port *F* registers with the air and gas ports *E* and *D*. By mov-

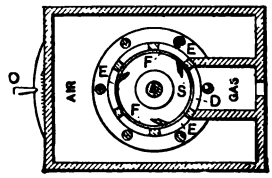


FIG. 118.

ing the lever *O* from the crank shaft, this piston valve is rotated, and the part *S* uncovers the gas port and covers the air port, so that any possible proportion of gas and air may be obtained without, in any way, reducing the area of the inlet ports. The guide carrying the lever *O* is graduated, so that the operator can always tell what proportion of gas and air is being used. With blast furnace or producer gas, the gas port might have to be as large as the air port, which is easily accomplished. The electric igniter (see Fig. 116) is so placed in the cylinder that a mixture free from exhaust always surrounds it, insuring proper ignition of the fresh charge, even at atmospheric pressure (see Fig. 109). As each end of each cylinder is a complete engine of itself, having a separate air, exhaust pipe, and igniter, any one or all of the explosion chambers may be used for producing the power required. By cutting off the gas from any explosive chamber, it ceases doing work; yet compression may take place therein, storing up the inertia of the reciprocating parts. By moving the lever *T* (Figs. 114 and 116) to a horizontal position, its exhaust valve is held open and the cylinder may be examined

or the igniter removed without stopping the engine. These levers are also used to hold the exhaust valves of the head end cylinder open when starting with the crank end cylinder, thus removing all compression. As the ports and valves are on the bottom, any surplus oil in the cylinder will be carried down and will lubricate the piston valves and stems. The crank shaft, cross head pin, crank pin, guides, and worm gears are lubricated in the following manner:

The worm gears are arranged to run in a tight-fitting case, one-half of which is made in the engine frame by babbitting around the blank before teeth are cut (Fig. 117). The oil from the basin under the crank shaft flows into the gear case and is carried up by the spaces between the teeth, but prevented from passing around by the teeth from the other gear, is forced through a system of pipes to the different sight feed oilers, as shown in Figs. 113, 114, 115, 116, and 117, and the half-tones. What oil is not used by the sight feed oilers is by-passed through the gooseneck high enough to give the oilers sufficient head, and flows through the strainer on crank case hood back into crank case basin. The crank pin and cross head pin are oiled by the overflow from the main bearings and the upper slipper in the usual manner. The design of the frame is such that all oil flows by gravity back to the settling chamber in the crank case basin; yet the crank and counter weights do not dip into the oil, so the working parts are as clean as if they were not enclosed. The cylinder oilers are of a special design that feed only when the engine is running, stop when the engine stops, yet the feed is always in sight; the quantity in the glass reservoir may always be seen, no pressure or smoke enters the bull's-eye or the reservoir, and the latter may be filled any time without shutting off the needle valve, thus changing the adjustment. From six to fifteen small drops per minute are found to be sufficient for a cylinder and its valves. The governor (Fig. 114) consists of two weighted inertia levers held towards the centre of governor pulley by one helical spring on a diametrical line with a right and left nut in each end, so that the tension may be adjusted by turning the spring. The governor arms are keyed to shafts, which extend through a bushed boss on diametrically opposite spokes (Fig. 117), and these shafts have radial arms, the ends of which connect by links to the driving gear, which is otherwise loose on the crank shaft. When the speed goes beyond normal

the weighted arms separate and the driving gear, as well as the driven gear, advances in time ahead of the crank shaft. This makes the cut-off earlier, and less gas and air are admitted to the cylinder; consequently, the speed is controlled. If the time of the side shaft advances ahead of the crank shaft, not only will the cut-off be earlier, but the time of every other operation controlled by the cams on this shaft will be advanced. The exhaust will open before the piston reaches the end of the working stroke and will close before it reaches the end of the eduction stroke, imprisoning some of the burnt gases, and the admission would also be earlier, but as the poppet cannot open until the pressure within the cylinder is reduced to atmosphere, the admission *begins later* and *cuts off earlier* when engine is cutting off, so that should the governor advance the side shaft 45 degrees, or until the cut-off was at one-quarter of the stroke, then the exhaust would close at three-quarters of the stroke, and no fresh charge would be admitted to the cylinder; and the lowest possible compression, should the admission be entirely cut off, is one-half of the maximum at full load. As the fresh charge becomes more diluted with the exhaust product it becomes a slower burning mixture, and the time of ignition should be earlier, for which the advance of the cam shaft provides.

Starting Mechanism.

If the size of the engine is such that the attendant can turn the flywheels by hand, it is started as follows:

The vertical lever just in front of the crank-end cylinder (Fig. 114) contains a pin and roller which run in the grooved collar on the cam shaft, and by moving this lever from the crank shaft the cam shaft *H* is moved longitudinally when the starting cams *L'* of the crank-end cylinder engage with the rollers *Y*, and a double igniter cam comes under each igniter rod *B*. This double igniter cam produces two ignitions at each end of the cylinder for each revolution of cam shaft immediately after cut-offs take place.

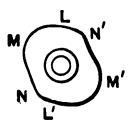


FIG. 119.

Fig. 119 is an end view of the cam *L'*, which admits and exhausts twice during each revolution of the cam shaft, producing the diagrams (Fig. 109). As soon as the engine has sufficient speed to compress a regular charge, the vertical lever is either

moved towards the crank, throwing the regular igniters and cams L into operation, or one end of the other cylinder is started, by throwing from a horizontal to a vertical position the lever T. When the cams L' engage with the rollers Y, the crank-end cylinder could be used for a steam or compressed air motor, having a fixed cut-off at half stroke, so if it were not found practicable in very large engines to start by turning the flywheels, compressed air could be used to get up sufficient momentum to start the head-end cylinder.

As the mean effective pressure of the starting diagrams is only about 6 pounds, the engine should start without load with from 8 pounds to 10 pounds air pressure, which is about one-fifteenth the pressure used for starting engines in which the regular compression must be overcome. Should circumstances arise in which it would be desirable to start the engine with full load, as in locomotive practice, then compressed air could be used in both cylinders with any predetermined pressure until the maximum speed is obtained, when, by simply moving the lever and opening the gas valve, it is immediately converted into an internal combustion engine with a noiseless exhaust.

General Conclusions.

As the mean effective pressure of an engine utilizing only about one-half a cylinder full of combustible mixture is about 60 per cent. of that of the ordinary gas engine, the cylinder capacity of an engine maintaining a higher efficiency by greater expansion must be nearly twice the capacity of the ordinary gas-engine cylinder for the same power developed; yet the same could be said of a steam engine utilizing the expansion of the steam compared to one without cut-off. However, as but one crank and lighter flywheels and double-acting cylinders can be used, it is probable than an engine of this type would not weigh more for the same output than the ordinary single-acting engines now on the market.

One of the disadvantages of the modern internal combustion engine advanced when comparing this type of motor with the steam engine is that it cannot be overloaded, and that its range of economy is greatly restricted. If a motor is giving out its full power and more is added, the motor will stop, as there can be no reserve when each induction stroke takes a

cylinder full of explosive mixture. On the other hand, the engine must not run below its rated capacity, or the efficiency will be greatly impaired. In other words, the economical range of the modern gas engine is at full load, for reasons heretofore pointed out. But if, instead of taking a cylinder full of combustible mixture as our unit of fresh charge, we design the engine so that two-fifths or thereabouts of a cylinder full of combustible mixture is sufficient for the average load, with the principle of utilizing the charge and governing pointed out, we will have a much greater range in which the engine may be worked without an appreciable loss in efficiency.

As the compression changes only one-half as fast as the cut-off with a change of load, we can have a reserve of power even if we do release considerably above atmospheric pressure, so long as compression does not go sufficiently high to cause premature ignition. Of course, loading such an engine beyond its normal capacity may even lower the efficiency, as in a steam engine, but sometimes the ability to carry an overload for a short time far outweighs the necessary loss.

The method of retaining the products of combustion to reduce the clearance and thereby raise the compression during light loads may be considered inadvisable by some authorities, yet others show by experiments that the inert gas has no injurious effect on the incoming charge, except possibly to make it a slower burning mixture, which, on account of our method of ignition, has no deleterious effect. With a fixed point of ignition and a slower inflammation as the load decreases, a limit to the piston speed is reached, and is given by some authors as 600 feet per minute. Yet it is evident that the quicker we can expand the gases the more heat will be turned into work, and the less will be transmitted to the cylinder walls; therefore, if we can advance the time of ignition, so that the maximum pressure takes effect at the beginning of the stroke, the piston speed may be materially increased and the jacket losses minimized.

While no exhaustive tests have been made to determine the actual thermal efficiency of the engine under different conditions and loads, a comparison of the amount of gas used per brake horse-power with that of the ordinary gas engine, shows a considerably higher efficiency, and the author hopes the results of an actual test may be presented to the Society at its next meeting.

From a mechanical standpoint, very little improvement could be desired. The $10\frac{1}{4}'' \times 19''$ engine which developed 50 horse-power with illuminating gas, running at a piston speed of 700 feet per minute, either light or loaded produced no perceptible vibration, though it was not anchored to the foundation, but merely rested on the wooden wedges used for levelling up the engine.

As the cams and rollers are always in contact, no noise arises from the cams striking the rollers, and though the poppet valves are inclined to rattle when seating, a proper adjustment of the air pressure by the pet cock in dash-pot guide will almost entirely overcome the noise.

The worm gears necessary for driving the cam shaft must run in oil to be efficient, and in doing so are noiseless, and make an ideal pump for circulating the oil to the engine bearings.

While the length of the engine is considerable, it is no more than that of tandem compound steam engines of the same stroke, and the height is such that no ladders or galleries are necessary for indicating or making accessible the working parts. The engine from which the half-tone illustrations were taken is fitted with a permanent reducing motion of such a design that pressing a spring starts the indicator drum, and pulling a string stops it.

No oil is thrown from the moving parts, and the working parts are not exposed to the evil effects of dust and dirt.

While the author may have dwelt too long on some points and neglected others, it is hoped that the ideas presented, the advantages gained by their fulfilment, and the means adopted for carrying them out, may be of interest to the Society.

DISCUSSION.

Prof C. V. Kerr.—The cycle used by Mr. Sargent is pronounced by Dugald Clerk in the course of his discussion of the various gas-engine cycles to be more efficient than the Otto, in which expansion is carried to the volume from which compression begins and less efficient than the one giving expansion to atmospheric pressure. But he can approach as closely as he desires to the ideal cycle and has therefore at once taken a long step in advance.

The plans tried by gas-engine builders to meet reductions of

load have been (1) to miss an explosion (2) to throttle the admission of a mixture of constant quality, and (3), as Mr. Sargent does, cut off the admission of a mixture of constant quality earlier in the suction stroke. The first method results in nearly constant heat efficiency from no load to full load, but the engine is sadly handicapped for modern work by great variation in speed. In regard to the second and third, they are both superior to the first in constancy of speed and there is little to make a choice, except we approach the question from the side of steam-engine practice and choose the automatic cut-off. Both, however, confess to lowering the efficiency, while the load is reduced because the compression is lowered. Tests confirm this.

Here let me say that I understand Mr. Sargent's statement on page 316 to be that efficiency increases with compression because while the volume of mixture admitted during suction remains constant the cooling surface absorbing heat from the burning gases diminishes with higher compression.

I would add a reason. The higher the compression with a given mixture the more intimate is the contact of combustible with oxygen, the quicker the combustion and the higher the initial temperature and pressure, thus approaching the condition of maximum heat efficiency. Thus in an engine using natural gas, the point of ignition was fixed. A compression to 24 pounds was followed by a maximum pressure of 27 pounds, while with compression to 112 pounds, the pressure ran up to 347 pounds. In an *oil* engine, compression to 22 pounds was followed by a pressure of 168 pounds and a compression of more than 30 pounds was found undesirable. On the other hand, engines using blast furnaces or producer gas find a high compression necessary. These effects are due to the difference in heating power of the fuel. In all cases, the highest safe compression should be used.

This point may be illustrated by considering the combustion of the common black gunpowder, which is an intimate *mechanical* mixture, in comparison with gun-cotton, nitro-glycerine or fulminate of mercury, which are intimate *molecular* mixtures. In the gas engine, the safe limit to compression is set by the increasing tendency of the mixture to explode or detonate instead of simply burning.

Before passing from this phase of the question I desire to pay tribute to Mr. Sargent's ingenuity in advancing the point of ignition as the quantity of mixture and the compression are reduced

for light load. The lower the compression the slower the combustion, and hence the earlier the ignition should be to secure the maximum pressure soon after the beginning of the working stroke. It is to be expected, therefore, that this engine will show higher efficiency at light load than any engine yet built which gives an impulse at each point in stroke regardless of the load.

I would venture to express the opinion, however, that to secure the maximum efficiency as well as maximum steadiness of speed at all loads it will be found desirable to use a poorer mixture and higher instead of lower compression, together with earlier ignition for the lighter loads. Practical difficulties in design or operation may defeat this. One thing is reasonably sure, this advance in time of ignition will enable any desirable piston speed to be used.

Any one who enjoys an exhibition of inventiveness will find an examination of the engine which embodies Mr. Sargent's new principle to be an intellectual treat. The governor appealed especially to me. It is simple, symmetrical and enables the use of *all* the inertia forces in harmony to effect quick regulation. The spring is not subject to bending under centrifugal force, and the centre of gravity may be put in the centre of the shaft and kept there regardless of position of weights.

Other points in design, such as the oil pumps, the cylinder oiler, and the packing for the stuffing boxes are likewise ingenious. Defects in design exist, however, such as the hot spot at each end of the cylinder at the bottom due to being uncovered by the water jacket, but this at least can be easily remedied; something more serious may exist, however, in the high explosion pressures felt just after the change from the Lenoir to the Otto cycle. To secure the engine against these, the safety valves shown in Fig. 111 at the groups of seven holes at each end of the cylinder were devised.

I have examined this engine in a financially disinterested spirit. It is well constructed, light in weight for the power developed, starts with the greatest ease, runs with a minimum vibration and variation in speed and regulates quickly. From the fact that any one or all of the cylinder ends may be used to develop power at the same time, the engine should show under test a wide range of load at its highest indicated efficiency. A phenomenon appearing in throwing an unused cylinder into service while running is found in the appearance of water at the cylinder cocks. The sec-

tion shown in Fig. 115 makes an accumulation of water due to leakage of glands impossible, as the exhaust valves are at the bottom of the cylinder and held open. The unused cylinder surrounded by the water jacket simply becomes a condensor for the water in the products of combustion.

When the engine is running at full load the exhaust temperature is found to be less than 350 degrees Fahr. at the cylinder, while at a pet cock in the exhaust pipe some 10 feet away the hand could be held in the escaping gases without discomfort.

Mr. Harrington Emerson.—I have driven a mongrel dog team on the Yukon and broken in wild horses on the plains, and had considerable to do with contractors' mules, which are a worse variety than the government mules; but I never struck anything which was quite so capricious as the gas or oil engine, and I am here to learn all I can about it. The principle proposed by Mr. Sargent, and apparently so successfully carried out, I think, has already been put somewhat into effect by Dugald Clerk in one of his engines, and one of the French engineers, Mr. Forest, has proposed exactly the same thing. He uses three cylinders, and as he compresses the charge in one, he passes a portion of the charge through valves actuated by cams over into another cylinder, so that he constantly, in the compression, is passing back and forth a portion of the charge to another cylinder, and securing in that way the advantage of expanding further than could ordinarily be done. In the gas engine, some of the troubles that we have, arise from the fact that it is so absolutely different from the steam engine. In the first place there must be perfect combustion in the cylinder—a problem not met in the steam engine. Secondly, there must be very high compression if there is to be high thermal efficiency. Thirdly, undoubtedly economy is secured by tremendous speed. Some of the little French engines run 2,500 revolutions a minute. In one of the engines of 5 horse-power that we designed, the valve had to open, the charge had to be admitted and the valve had to close in the one hundred and thirty-second part of a second, and the speed of the exhaust gases was 38,000 feet a minute. Fourthly, the gas engine is at its maximum efficiency in practically small sizes. I think the most efficient gas engine or oil engine, which is, of course, included in it, which has ever been built was of 30 horse-power only, and when these small powers are exceeded, something seems to take place—whether it is difficulty of ignition or difficulty of mixture—the

efficiency falls off. In some of these existing little engines of only two or three or four inches diameter, a very high efficiency is obtained, owing to the perfection of the combustion. Now I would like to ask Mr. Sargent if he does not think that the rarefaction of the air due to the heated cylinder in many cases accomplishes almost what he has been striving for. Is not less mixture admitted? Isn't it equivalent practically to an earlier cut-off of admission?

Mr. Sargent.—I think not. I do not know of any other engine that cuts off the admission entirely at some part of the stroke. Many engines throttle the mixture, but in that way there is a loss.

Mr. Emerson.—No, not in throttling; I mean by cut-off. Supposing you take the ordinary engine, and you admit the vapor or the gas into this very hot cylinder, isn't it expanded to such a degree that you do not get a full charge? Don't you get really a much reduced charge, owing to the fact that it comes into such a hot place?

Mr. Sargent.—You always get a reduced charge, because it is never at atmospheric pressure.

Mr. Emerson.—I mean owing to the expansion due to the heat.

Mr. Sargent.—Some; yes, sir.

Mr. Emerson.—Would not that, in many engines, to a certain extent, accomplish the results you have obtained?

Mr. Sargent.—The diagrams taken from them do not show it.

Mr. Emerson.—Of course that would be the best way of getting at it. But I imagine there might be very important changes due to expansion of the charge.

Mr. Sargent.—The tendency in rarefaction is to cool the gases.

Mr. Emerson.—Not when expansion is due to heat from walls of combustion chamber.

Mr. Sargent.—Of course the gases are heated some as they come in, but they are heated much higher by compression.

Mr. Emerson.—That is true. But if you admit a cool gas into an intensely hot cylinder, do you get as large a charge as theoretically you ought to?

Mr. Sargent.—Theoretically, we do not want to have a cylinder full.

Mr. Emerson.—Well, do you get much more than half a cylinder full with the cool gas?

Mr. Sargent.—Yes, sir.

Mr. Emerson.—You think so?

Mr. Sargent.—I think so.

Mr. Emerson.—I think in some of my experiments I did not get more than half a cylinder when I wanted a full cylinder.

Mr. Sargent.—If you notice, the compression ordinarily begins at the end of the induction stroke when a full charge is drawn in, but, of course, it may be heated up some, so that the real volume is less.

Mr. Emerson.—I am really anxious to find out, as I suppose many of you are, in regard to the operation of gas and oil engines, and I would like to ask some questions of Mr. Sargent. Has it been your experience that the greatest loss is in the exhaust instead of in the cooling water?

Mr. Sargent.—It depends altogether on the dimensions of the cylinder. In a square cylinder, the greatest loss is in the exhaust. In a cylinder twice as long as the diameter, the greatest loss is in the jacket.

Mr. Emerson.—That has been your experience in that matter?

Mr. Sargent.—Yes, sir.

Mr. Emerson.—I supposed that nearly 50 per cent. was lost in the cooling water, and only about 25 per cent. in the exhaust.

Mr. Sargent.—Referring to the paper that was read here a year ago, 57 per cent. was accounted for in the exhaust, and about 25 per cent., I think, in the cooling water. Square cylinders were responsible for these proportions.

Mr. Emerson.—That was very astonishing. I saw that reference. I was not here a year ago. A loss that is not mentioned, I think, by you is one of the chief losses that occurs in the cylinder, and that is due to the incomplete combustion. It certainly does not go out in the exhaust when it deposits in the form of carbon inside the engine, which is just the place where we do not want it.

With reference to balance, which is one of the most important things in all gas and oil engines, you say that there is no vibration in this tandem engine. Now, why not? It seems to me that the tandem arrangement is the very one that would produce the most vibration.

Mr. Sargent.—Because the conditions are practically the same as in a steam engine. In this tandem engine you get compression every stroke, which neutralizes the inertia of the reciprocating parts; while in the single cylinder trunk-piston gas engine you have compression every fourth stroke only. In the tandem engine you have a compression for every impulse, and the inertia of

the pistons and rod caused by the latter is absorbed by the compression rather than by the main bearings of the crank-shaft.

Mr. Emerson.—That is very true. You get a compression in every single stroke balancing that way.

Mr. Sargent.—Yes, sir.

Professor Jacobus.—A question has been asked in regard to whether the full charge of gas and air corresponding to the cylinder dimensions and pressure shown by the indicator diagram enters the cylinder of a gas engine. This can be determined by experiment if the volume of the air which enters the engine is determined as well as that of the gas. The weight of the entering charge can also be computed if we know the analyses of the gas used as fuel and of the exhaust gases. The only case that I know of where the air was accurately measured in the test of a gas engine was in a test made some time ago by Messrs Brooks and Steward as a graduating thesis at the Stevens Institute of Technology. From data derived from this test it appears that the volume of the charge of gas and air which entered the cylinder was very nearly equal to the volume as shown by the indicator cards, provided the heating effect of the exhaust gases retained in the clearance space is allowed for: the temperature of the latter being assumed to be that of the gases in the exhaust pipe. The jackets, therefore, acted to such an extent in cooling the walls that they made the complete filling of the cylinder possible.

Mr. J. F. Max Patitz.—The cycle described by Mr. Sargent is not new. It was proposed by O. Köhler before the year 1890, and several gas engines working on this principle have been built by the Gasmotoren-Fabrik Deutz, but the results have not been better than with the regular Otto engine.

At present, Körting Bros., in Hanover, build gas engines according to this cycle, and regulate their engines in the manner proposed by Mr. Sargent. See Professor Schöttler's book, "Die Gasmachine," third edition, pp. 76 and 143.

Prof. Sidney A. Reeve.—I should like to say in regard to the general tenor of the paper that I am very glad indeed to see the appearance of this engine. It has been an attitude that I have maintained for a number of years that we could not possibly expect a single-cylinder Otto-cycle engine to develop into a modern prime mover. The gas engine, from its thermal efficiency, is naturally classed as in competition with triple-expansion or com-

pound condensing steam engines. Now, these engines have always two separate main cylinders, and often three or four, and if we bring in the feed pumps and air pumps the total number of cylinders becomes from four to ten, or more. There is no hesitation on the part of the buyer or engineer to face the necessity for this whole roomfull of machinery in order to produce large amounts of power at these high efficiencies. At the same time it is true from many other considerations, chiefly mechanical in nature, that the gas engine must assume the general multi-cylinder form of construction before it can hope to successfully compete with the steam engine in an attempt to produce the same results; that is, results both thermal and mechanical.

I also might note a few instances in addition to those already mentioned which show that the principle underlying the operation of the engine is not at all new. There is the Charon engine, a French engine, which has been in existence the last twelve years, I think. It is described in Mr. Witz's book on gas engines, which I find is in the library of the society. Then there are Mr. Atkinson's famous engines, the differential and the cycle. While they were not successful mechanically, yet they developed these higher thermal efficiencies. I do think that none of the engines mentioned have developed the opportunities which the cycle presents in the way in which the engine described by the author has done, and I think he is to be congratulated upon the apparent engineering taste and judgment with which he has developed these features.

I might criticise him to the extent of reminding him that the thermodynamic efficiency of the cycle is not given by the expression $\frac{T_1 - T_2}{T_1}$ which measures that of the ordinary Otto cycle when T_1 is the initial and T_2 the final temperature of expansion. The cycle of the author's engine is an irregular one, and the efficiency equation has to be modified from the ordinary one.

I should also like to say that the public is undoubtedly waiting very anxiously for thermal tests from this engine, and I would ask Mr. Sargent if he has not been able to make some since the paper was prepared.

I would also say to Mr. Emerson, who asked as to the condition in which the charge enters the engine, that I think the only measurement of the conditions existing in the cylinder during the suction-stroke, which has come to my attention, appeared in the

Philosophical Magazine, for September or October, 1895. They were reprinted in this country by the *Progressive Age* in its issue for February, 1896. They record some very fine determinations of temperatures existing in the cylinder at various points of the cycle, and by knowing the temperature we can know the rarefaction of the incoming charge.

Prof. Wm. T. Magruder.—I wish to congratulate the author on the improvement which he has effected in the throttling method of governing a gas engine, and on the number of times he is able to expand the charge by his scheme. It is to be hoped that he will favor the society with an additional paper giving the results of tests of the engines with fixed and variable loads. May I inquire what are the causes of the differences in the two sets of cards given in Fig. 107, and why, in the lower set, the greater the forward pressure the later in the stroke is the maximum pressure reached? This would seem to indicate a decrease in inflammability with increase of compression. It is to be noted that none of the diagrams indicate a pressure greater than 240 pounds per square inch, even with 80 pounds compression, or a ratio of 3 to 1. Compared with the diagrams given in Professor Kerr's paper No. 880, this ratio would seem to be low, but possibly the author may explain it and state what kind of gas was used.

In the last paragraph of page 315 of the paper, he speaks of the "release being at 1,200 degrees Fahr." From observations taken of the interior of a gas engine while running, and from pyrometric determinations of this temperature I am inclined to the opinion that it is considerably higher than 1,200 degrees Fahr., and would be glad to obtain experimental proof or disproof of this commonly accepted figure.

Mr. Lewis H. Nash.—I would like to call attention to the difference between this engine of Mr. Sargent and the engine that throttles its charge.

In the 4-cycle engine we have four distinct operations. First, the suction stroke; second, the compression stroke; third, the power stroke; and fourth, the exhaust stroke. Now, the only difference between the throttling engine and the cut-off engine lies in the first or suction stroke. That is to say, if, in each case, the engine is to have a cylinder full of combustible mixture under an absolute pressure which may be indicated by a point P upon the indicator diagram, then the line of compression for each

engine would be indicated by the line *Pc*, the power stroke by the line *cDe*, and the exhaust by the line *eA*.

Now, for the suction stroke the cut-off engine will give a line *aBP*, while the throttle engine will give the line (shown dotted) *AP*. Thence the area of the portion of the card included in the triangle *aBP* represents the total gain in power due to the cut-off feature of the engine over a similar engine throttling the charge.

Mr. Arthur J. Frith.—I would like to ask Mr. Sargent exactly where the thermometers were placed in reference to the exhaust valve, as I find that the temperatures taken by thermometers are unreliable and do not correspond, even approximately, to the temperature of the exhaust gases. I believe it is incorrect to use, as Mr. Sargent does, the reading of the thermometer as data for a discussion of the efficiency of the engine, since the temperature

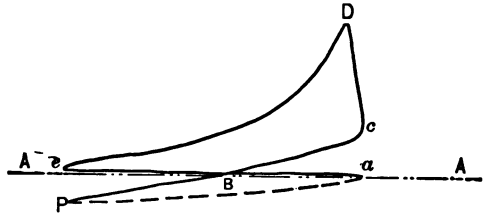


FIG. 120.

has dropped enormously from that at the end of a power stroke to the temperature of the gases where the thermometer was placed. The cooling of hot gases by running through pipes or other orifices is exceedingly rapid, and as these temperatures have to be taken probably on the further side of the exhaust valve, they are cooled by the valves themselves, and by the water-jacketed surfaces over which they run. In fact, in engines where I am satisfied that the terminal temperature was something like 1,000 or 900 degrees, at 10 or 12 feet from it, you could easily hold your hand over an opening, if it were small. That did not mean that the temperature of the exhaust gases thermo-dynamically speaking, were low, but that the temperature had been lost in the passages. It ought to be understood that the temperatures taken are not even approximate. In discussing these cycles theoretically, there is no reason to expect with the ordinary gas engine cycle of an explosion engine such as this that a particularly low temperature could be reached, even if it were expanded down to

the atmosphere. The cycle is far from being thermo-dynamically perfect, and as it does not promise a low terminal temperature, I doubt very much if it is actually obtained. If the thermometers show low figures, it is simply because the exhaust gases are cooled by coming through apertures, the temperature of which is very much less than that of the exhaust gases.

Mr. Emerson.—I would like to say just one word more, because I have tried that same thing. I have tried with a thermometer to find the temperature of the exhaust gas, and I could hold my hand in the gases of the engine I was experimenting with within 6 inches of the exhaust valve without being burned, and it looked to me that the temperature was not over 150 degrees, when theoretically it ought to be very much higher.

In respect to Mr. Sargent's engine, it seems to me one of the most important things that that engine has shown is that this inimical vibration of the gas engine is due to the unbalanced reciprocating parts, because there are certain other things that he has not balanced. He certainly does not balance the change of the centre of gravity of the engine, and he does not balance the reciprocation. That, of course, you cannot balance in an engine of that kind. But apparently, if it runs. smoothly, it is evident to me that the vibrations that are occurring in these other engines, the vibrations noticeable in these small automobile engines, must be due to the unbalanced reciprocating parts.

I have just received a report on one of the Diesel engines in Germany. It was a 36 horse-power engine. It was run up to 40 and down to 7 horse-power, with practically the same economy. With 7 horse-power there was a larger consumption of fuel, but at 40 horse-power there was simply an inappreciably greater consumption of fuel than at 30. So that in the Diesel the variable load is combined with maximum economy. For some time I have had in mind an arrangement of three cylinders tandem, all double acting. The larger low-pressure cylinder is nearest the crank, the other two are both high pressure and alternately exhaust into the low pressure, which expands the charge to atmosphere.

Some of the advantages of this arrangement are that it lends itself admirably to water cooling, not only of walls and valves, but also of long piston rods and pistons, that packing is facilitated, as it is easy to pack between cylinders, where leaks are not fatal if they should occur, easy to pack the piston rod as it emerges from the low-pressure cylinder.

In an engine of this design there is a double impulse every stroke; namely, an explosion impulse from one of the low-pressure cylinders and an expansion impulse from the exhaust in the low-pressure cylinder.

An engine of this design would be as powerful as a five-cylinder single-acting engine for the same quantity of fuel, would be very much cheaper to make, simpler to operate, and would show much less vibration.

Professor Jacobus.—Mr. Frith was certainly right in what he said about the difference of temperature which may exist at the point of release and in the exhaust pipe. In the particular case I have already referred to, there was a difference of 1,200 degrees Fahr. The temperature of the exhaust gases was measured by a pyrometer, and that at the release point computed by an accurate method where the total weight of the working charge, as determined from the measured volumes of the gas used as fuel and the air entering the cylinder, was made one of the factors.

Mr. Sargent.—Relative to the remarks of the last three gentlemen in regard to the exhaust temperature I would say that the proper place and time to take the exhaust temperature is before the exhaust valve opens; because after it opens there is expansion and a drop in temperature. There must be a greater drop in temperature after the exhaust valve opens in the engine, from which diagrams Figs. 101 and 102 were taken, which is exhausting at 45 or 50 pounds absolute than in the engine under discussion that exhausts at 18 to 20 pounds absolute; so that in reality there is a greater difference between the exhaust temperatures than that which is recorded by the thermometers, even if they are the same distance from the exhaust valves. The temperature of the exhaust of the engine referred to in the first part of this paper is 1,200 degrees Fahr. and the thermometer—a copper ball, was placed in the exhaust pipe as close to the engine as possible. Although the temperature of release was as high as 1,200 degrees, it surely was a great deal cooler than the temperature of the exhaust before the exhaust valve opened, and expansion from 40 to 15 pounds absolute took place.

The mercurial thermometer, if you will notice the half-tone Fig. 111 of the engine herein described, passes through the cylinder shell into the exhaust passage, and the discharged gases pass over the thermometer before they reach the exhaust pipe. If you are running one end only of the cylinder you do not get as high an ex-

haust temperature, even with the same terminal pressure, because part of the time the thermometer may be cooling off, but with both ends working and a continuous exhaust striking the thermometer, the highest temperature that we get is 400 degrees Fahr., and at the time that Professor Kerr saw the engine operate no water was used in the jackets. I have run the engine with no load without any cooling water for half an hour at a time, trying to melt out the lead piston-rod packing and could not do it on account of the low average pressure and temperature.

Now, it has been suggested that this cycle has been proposed before. That is true, if by this cycle is meant complete expansion. So was the Otto cycle proposed fourteen years before Dr. Otto put it into practice. All gas-engine authorities say the proper thing for economy is to get as complete an expansion as possible. That is a fundamental principle laid down by Beau de Rochas, the author of the Otto cycle. The Acme people compounded the gas engine, and got a low terminal pressure. Mr. Atkinson got low terminal pressure—25 pounds absolute, and the highest economy ever attained at that time. But there is not, to my knowledge, a single diagram shown of an engine in which you get complete expansion by cutting off absolutely the gas and air at some predetermined part of the stroke. I have all the latest English works on gas engines. I have been trying to find some one that has done this and has got as low a terminal pressure. In fact all the authorities—Donkin, Clerk, and several others, say that a complete expansion has never been obtained.

Relative to the efficiency of this engine, I will state that I have never had any chance to make a thermal efficiency test, but I have made a comparative test with another single-cylinder trunk piston Otto cycle engine, whose effective cylinder capacity was practically the same; but of course the horse-power was only one-quarter of the engine in question. With the jacket water at the same temperature in each case, we got 12-brake horse-power with the 9-inch by 14-inch engine on 28 feet of illuminating gas per horse-power hour, and with the 50 horse-power engine under consideration between 19 and 20 feet of gas per brake horse-power hour. One test gave 19½ and the other 19 9-10 feet. That shows a great deal better comparative efficiency than we anticipated. I do not know anything about the heat units of the gas at that time. Rival companies were at war; they were selling illuminating gas at 40 cents a thousand. Whether they changed the quality or not I

do not know. At any rate, the gas company probably did not lose anything. The City Electrician at the time, in testing the gas, found it below candle-power as called for by the city contract.

*The loss to which Mr. Emerson refers—the deposit of carbon in the cylinder—should not be considered in accounting for the disposition of the heat in the fuel, for the reason that this deposit should not occur, and will not with perfect combustion, which is the result of a proper mingling of a correct mixture before ignition.

Considering such a loss is like considering the loss of pressure caused by a leaky valve or piston. It should not, and need not, exist.

Referring once more to that question of the expansion by heat of the gases during suction-stroke, would say that the difference in temperature between the cylinder walls and the fresh charge is so little, compared to the difference during inflammation, that there should be a very small transmission of heat from one to the other; and the experiments to which Professor Jacobus refers corroborate this theory.

If Mr. Emerson's experience has been that he gets only half a cylinder full of combustible mixture, I think he must have been experimenting on that French engine to which he refers, which runs 2,500 revolutions per minute, and had such small valves that the speed of the gases was over 600 feet per second. It was no wonder the cylinder did not fill.

I do not agree with Mr. Frith that the temperatures of the exhaust taken are not even approximate. If the temperature varies with the pressure, which is self-evident, they must be, in a measure, a criterion as to comparative efficiency.

If the pressure of release approaches atmospheric pressure, more work is delivered; and, naturally, we would expect more heat to be turned into work, and the temperature of the exhaust gases is sufficient evidence of the economy of this cycle over that of engines that release at 25 to 40 pounds above atmosphere.

I think, contrary to his opinion, that we have every reason to expect a low temperature if we can expand to atmospheric pressure.

In the Charon engine, referred to by Professor Reeves, a more

* Author's closure, under the Rules.

complete expansion than ordinary is obtained by driving out into a separate chamber during compression part of the combustible charge.

The nearest approach to the cycle which the author has used is that suggested by Köhler, to which Mr. Patitz refers, but in this case, as well as in the Charon engine and all throttling engines, the compression varies with the amount of fresh charge admitted, and the point of ignition remains constant.

No. 880.*

NOTE ON CENTRIFUGAL FANS FOR CUPOLAS AND FORGES.

BY WILLIAM SANGSTER, BOSTON, MASS.
(Junior Member of the Society.)

In hardly any other class of machinery is the method of application of so great importance as it is in the case of centrifugal fans. The conditions of one installation are usually so different from those of any other that hard and fast rules are out of the question.

The writer, however, offers the following formulæ for the power required by centrifugal fans in cupola and forge practice with the hope that they may prove of service when laying out the power plants of shops, etc. They will be found fairly reliable, with the error as a rule on the side of safety.

Cupola Fans.

The amount of air required to melt one ton of iron in an ordinary cupola is variously estimated at from 30,000 to 45,000 cubic feet. In order to obtain a safe formula the writer has assumed this value at 40,000 cubic feet per ton. By ordinary cupolas are meant those which melt up to 6 or 8 tons per hour. Since the pressure of blast increases with the diameter of the cupola, and the power required to deliver a given quantity of air increases with this pressure, the formula is expressed in unit terms of 1 ton of iron melted per hour with a blast pressure of 1 ounce per square inch.

Assuming that a cubic foot of air at atmospheric pressure and at a temperature of 50 degrees Fahr., weighs .078 pounds, we obtain for the height of a column of air corresponding to a pressure of 1 ounce per square inch,

$$\frac{144}{16 \times .078} = 115.4 \text{ feet.}$$

* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

The velocity of air in feet per minute due to that pressure may be expressed

$$V = 60\sqrt{2gh}.$$

Substituting their proper values for G and H we have

$$V = 5{,}160 \text{ feet per minute.}$$

As each ton of iron melted per hour requires 40,000 cubic feet of air, that is, at the rate of 667 feet per minute, we shall require as the necessary area of orifice to deliver this amount at 1 ounce pressure,

$$\frac{667 \times 144}{5{,}160} = 18.6 \text{ square inches.}$$

The horse-power required will be expressed by the formula:

$$\text{H.-P.} = \frac{VAP}{16 \times 33{,}000 \times C} \quad \ldots\ldots \quad (1)$$

in which V = velocity of the air in feet per minute.
A = area of the orifice in square inches.
P = pressure of the blast in ounces per square inch.
C = coefficient of efficiency, allowing for friction of fan, belting, air in piping, etc., in this case assumed at 60 per cent.

Substituting the proper values in the above formula we have

$$\text{H.-P.} = \frac{5{,}160 \times 18.6 \times 1}{16 \times 33{,}000 \times .60} = 0.3.$$

Since the velocity of air varies as the square root of the pressure, and the area of the orifice for a constant quantity varies inversely as the velocity, it follows that the horse-power required to deliver a given quantity of air will vary directly with the pressure, or since VA is a constant, the power will vary directly as the pressure P. To obtain the horse-power required by a cupola fan we may therefore use the following formula:

$$\text{H.-P.} = 0.3\ TP,$$

in which T = tons of iron melted per hour.
P = pressure of blast in ounces per square inch.

Forge Fans.

For ordinary forge fires an allowance of 140 cubic feet per minute is ample. The usual pressure of blast is about 4 ounces per square inch. The velocity of air under this pressure, calling that of 1 ounce 5,160 feet per minute, will be

$$5{,}160 \times \sqrt{4} = 10{,}320 \text{ feet per minute.}$$

The area of discharge orifice equals

$$\frac{140 \times 144}{10{,}320} = 1.95 \text{ square inches.}$$

The horse-power required (from Equation 1) equals

$$\text{H.-P.} = \frac{10{,}320 \times 1.95 \times 4}{16 \times 33{,}000 \times .60} = 0.25,$$

or a safe allowance is $\frac{1}{4}$ horse-power per forge.

Smoke Exhausters.

Modern forge shops are equipped with exhaust systems for removing the smoke and gases from the fires, and delivering the same at some convenient point outside the building. In order to accomplish this result it is necessary to remove a larger quantity of air than is supplied by the blast, and the fan should be run at a low peripheral velocity.

A safe approximation will be to exhaust four times the air supplied by the blast, and to drive the fan at a peripheral velocity corresponding to a pressure of $\frac{3}{4}$ ounce per square inch. Since the horse-power required by a fan under constant pressure varies as the quantity of air delivered, and, as the pressure of blast when the quantity is constant, we find that if the fan removes 560 cubic feet at $\frac{3}{4}$ ounce pressure we shall require for each forge

$$\text{H.-P.} = .25 \times \frac{560}{140} \times \frac{.75}{4} = .19 \text{ H.-P.}$$

or a total allowance of .44 horse-power per forge.

On account of the diminished first cost some installations have been provided with but one fan for both the blast and the exhaust systems. Such an arrangement is not economical, since a much larger volume of air must be raised to the higher pressure than if a separate fan had been used for the exhaust system.

In the case given above we should have to handle five times 140 cubic feet of air at 4 ounces pressure, requiring 1.25 horse-power, instead of .44 horse-power for each forge. Even in a small system the power saved by the extra fan will pay for its cost in less than a year's time.

Overloaded Fans.

One of the most frequent errors, and also the most expensive, of which a fan user is guilty, is the speeding up of a fan which is too small for its work. It is such a simple remedy for an

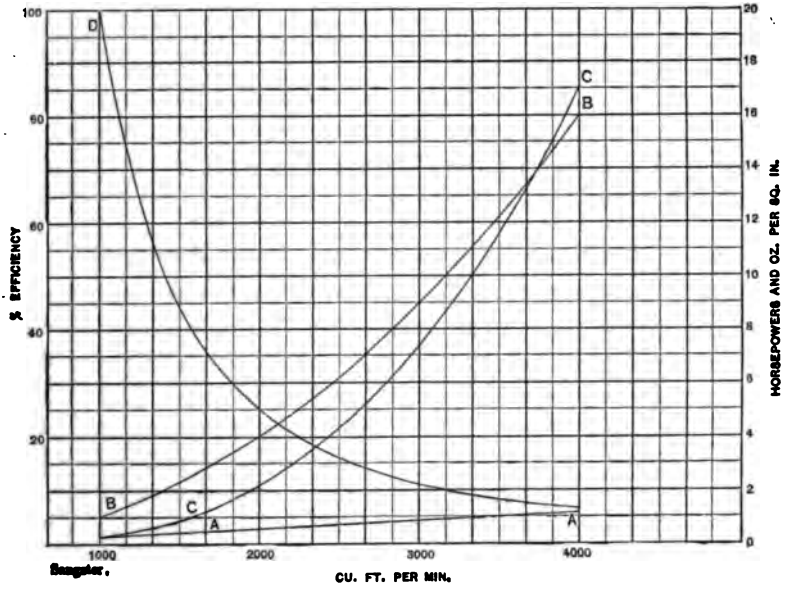


FIG. 121.

insufficient air supply that the consequent loss of power and lower efficiency is usually overlooked.

The diagram (Fig. 121) shows the theoretical horse-powers and pressures required to deliver volumes of air varying from 1,000 to 4,000 cubic feet per minute. Curve *A* represents the power required to move this air at 1 ounce pressure; curves *B* and *C* the pressures and powers required to deliver a varying volume through a constant orifice; *D* the curve of useful work in moving volumes of air at low final pressures by a fan of inadequate capacity, which has therefore to be driven faster to handle the air.

Curve *A* varies directly as the vol ures and

C as the cubes of the volumes; while D varies inversely as the squares of the volumes.

These power curves have been calculated from equation (1) with no allowance for friction, and are shown for pressure ranging from 1 to 16 ounces per square inch.

A fan too small for its work is usually overspeeded from 25 per cent. to 100 per cent. As shown by curve D, this represents a loss in efficiency of from 36 per cent. to 75 per cent. Take an extreme case, say a fan of 1,000 cubic feet capacity at 1 ounce pressure; by trying to move with it 4,000 cubic feet, we shall require 16 times the pressure and 16 times the power required by a fan of the proper capacity, with a corresponding efficiency of but 6¼ per cent.

Another loss in an overloaded fan occurs at the inlet. This waste is due to the head required by the velocity of the incoming air, and is shown by the diagram (Fig. 122), and dwelt upon more fully in the next paragraph.

Relation of Outlet Pressure to Outlet Area.

When used as a blower the ratio of outlet to inlet of a centrifugal fan should be so proportioned that air enters the fan with the least possible velocity. Up to a certain area of outlet, varying with the style of fan, the pressure of the outlet remains nearly constant. Beyond this point the pressure gradually drops until the full area of the fan outlet is reached. This drop in pressure is caused partly by the resistance of the air passages of the fan, but more particularly by the vacuum within the fan inlet. This vacuum is necessary to maintain the velocity of the incoming air, and represents a loss in effective pressure as well as in the efficiency of the fan.

In his work on "Centrifugal Ventilating Machines," Murgue remarks that all of the resistances within a fan may be represented by a thin plate having the necessary equivalent orifice. In a blower this represents a further reduction of inlet area and in the volume of air handled.

Slightly modifying Murgue's formula, and calling

P = pressure corresponding to the tip velocity of the wheel,
P_0 = pressure at the outlet,
P_1 = vacuum at the inlet,
A_0 = area of the outlet,
A_1 = area of the inlet,

we have for the pressure at the fan outlet

$$P_0 = \frac{P}{1 + \frac{a_0^2}{a_0^2}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and for the vacuum at the fan inlet,

$$P_1 = \frac{P}{1 + \frac{a_1^2}{a_0^2}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The total horse-power input to a fan is the sum of the horse-powers at inlet and outlet plus the power lost in friction, belting, etc. The latter factor increases with the load.

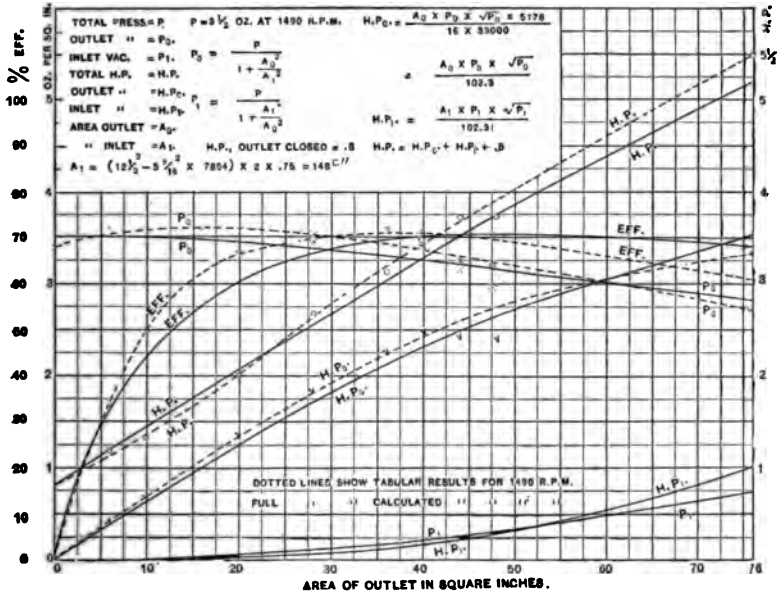

% EFF.
OZ. PER SQ. IN.
H.P.
TOTAL PRESS. = P
OUTLET " = P0.
INLET VAC. = P1.
TOTAL H.P. = H.P.
OUTLET " = H.P0.
INLET " = H.P1.
AREA OUTLET = A0.
" INLET = A1.
H.P., OUTLET CLOSED = .8
H.P. = H.P0. + H.P1. + .8
DOTTED LINES SHOW TABULAR RESULTS FOR 1490 R.P.M.
FULL " " CALCULATED " " " "
EFF.
AREA OF OUTLET IN SQUARE INCHES.

FIG. 122.

Mr. H. I. Snell* has given the results of some tests of a centrifugal fan, and these have been corrected for a uniform speed of 1,490 revolutions per minute and plotted, as shown in the diagram. Fig. 122.

The horse-powers at the outlet have been calculated from the outlet pressures, corrected to a uniform speed. The dotted lines

* *Transactions* American Society of Mechanical Engineers, vol. ix., page 51.

(Fig. 121) show the averages of the results. It will be noted that at the areas of 44 and 48 square inches the results fall below the curves. This is probably due to the slippage of the belts. The full lines show the curves as calculated from the pressures given by the Equations 2 and 3. The actual pressure at full outlet is lower than that given by the formulæ with a corresponding loss of efficiency. This is probably due to the increased friction of air within the fan.

The inlet area has been taken at 75 per cent., since the pulleys form short approaches for the entering air. The full outlet has been calculated at 85 per cent. of the actual area. The loss of power by friction, etc, has been taken as a constant .8 horsepower. The velocity of air at 1 ounce pressure per square inch has been given at 5,178 feet per minute, as per Mr. Snell's table. These deductions are of course crude, but may serve to illustrate one of the principal losses in an overloaded centrifugal fan, *i.e.*, the loss due to maintaining the necessary depression within the fan inlet in order to give sufficient velocity to the entering air.

This loss increases rapidly with the increased ratio of outlet to inlet areas, and in a fan with equal areas of inlet and outlet about as much work will be expended in drawing the air into the fan as in expelling it.

DISCUSSION.

Mr. Henry I. Snell.—Papers of this class are certainly interesting, and if from them we can obtain facts and figures, derived from cases in actual practice, they become very valuable.

They are contributions brought to our meetings, and dropped into the treasury of our *Transactions*, subject to future draft by any of the members, when needed for comparison with their own work, to give a value to the constants in their formulæ, or to guard them against erroneous assumptions or assertions.

Mr. Sangster's paper treats upon a subject about which much has been written; of which little is known.

A foundry is a dirty place, a busy place, sometimes dangerous; where visitors are always in the way, and seldom welcomed. If we want information it is easier to call the foreman one side, and from him obtain our facts. We learn he puts in so many pounds of fuel for a bed, so many pounds of iron, then fuel and iron

alternately, until he comes to the charging door, and he has a total of so many pounds of fuel and iron; all weighed by the wheelbarrow, or space filled, in the cupola; he then starts up his blower, and the manufacturer of it has said in his catalogue if it is run so many revolutions it will give so much pressure. So we get the real information of what is the best practice from a practical man, who has had twenty or thirty years' experience in all kinds of work, with all kinds of cupolas, all kinds of blowers, all kinds of charging, all kinds of products; and we are assured the methods he is using in this foundry are the best. We go away satisfied. We are down on the ground floor; we know it all. Perhaps we would remain satisfied unless we visit another foundry, and talk with another melter, who has had twenty or thirty years of varied experience, and has satisfied himself that a furnace should be charged, and handled so and so, entirely different from our first friend's experience.

We might visit twenty foundries, find twenty long and varied experiences, all different, all claiming to have the best methods, and getting the best results, and come away with the firm conviction that we do not know it all, or that melting iron in a cupola is an uncertain or mysterious art; or that a great desideratum is a collection of observed facts and measurements thrown into the cupola of intelligent examination by analytical scientific minds.

These remarks are not overdrawn, and apply to perhaps 90 per cent. of the foundries; not to the 10 per cent. where the melters are observers, students with opportunities; where system and knowledge is connected with their duties, and where money, in large amounts, is saved.

This question of the amount of power required to drive a centrifugal fan, or any other kind of blower in cupola practice, is difficult to solve by means of a formula—so many varying conditions enter into the problem. Mr. Sangster has made his contribution of 40,000 cubic feet of air per ton of iron; but to solve his problem we must have the required air pressure—an unknown or disputed quantity—the value of which we must assume. On this point, will some of the members pass in their contributions?

A question of vast importance, and worthy of careful consideration, is the selection of the cupola, the charging of the same, arrangement of the tuyeres, and the selection and application of the blower. The man who makes consideration of the first cost of his instalment the determining feature, is "penny wise and

pound foolish." With a proper instalment, it is quite reasonable to assert that in most any size of cupola for most any kind of product a successful melting can be obtained with an air pressure perhaps as low as 4 or 5 ounces per square inch, instead of 10 to 16 ounces now generally used.

Mr. Sangster's formulæ are based upon his assumption of 40,000 cubic feet of air per ton of iron.

If we substitute some other quantity in lieu of 40,000 cubic feet we change all the subsequent values given in his paper. I, therefore, hope that discussion may bring out some information upon this point, and as my contribution I will give the result of at least one test that will throw some light on this question. Given a plain cylinder cupola, 40 inches inside diameter when first lined up, but at time of test burned out so the actual inside diameter was 44 inches; a wind box surrounding same with a cross section of 14 by 15 inches, from which connections lead to 5 tuyeres, each 5 inches by 7 inches; height from bottom plate to bottom of charging door 12 – 6 inches; charge: first, a bed of 800 pounds of coke, then alternately 2,000 pounds of iron ($\frac{1}{2}$ pig, $\frac{1}{2}$ scrap) and 200 pounds of coke, until 5 charges of iron, or 5 tons, brought it to the charging door; a No. 8 Sturtevant Steel Pressure Blower at quite a uniform speed of 1,800 revolutions per minute, equivalent to a blast pressure of 11 ounces when discharging through apertures within the capacity of the blower—round galvanized steel air pipe, 16 inches in diameter, 1.4 square feet area, about 75 or 80 feet long, with 3 or 4 elbows of long radius; temperature of air entering blower, 50 degrees Fahr.

The results of a careful test are shown on the following diagram (Fig. 123), which gives the air pressure in ounces per square inch taken from the main pipe midway between blower and cupola, and the volume of air passing same point in cubic feet per minute, from observations made at intervals of 5 minutes throughout the heat. The results shown by this test are not ideal, or perhaps desirable ones, but you will note that the iron was melted quite rapidly and was very hot.

The labor time sheets probably will show no money loss in waiting for iron.

Possibly suggestions may be made whereby improved conditions can be obtained in our cupola practice. We often obtain better knowledge from our failures than from our successes.

Possibly in this case better results will be obtained by reducing

the speed of the blower to 1,250 revolutions, equivalent to a 5-ounce blast, and use not more than one-half the horse-power to drive it.

From the above test it will be seen that we melted 10,000 pounds of iron, and used 215,475 cubic feet of air, or 43,095 cubic feet per ton.

Observe that for the first 25 minutes only 2,200 pounds of iron

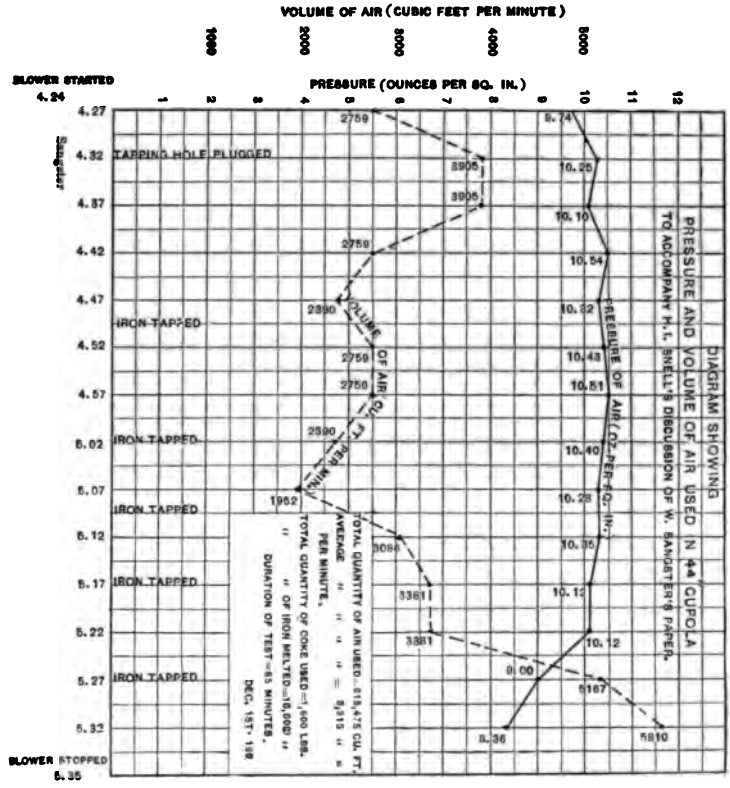


FIG. 123.

were ready to be drawn off; also at the latter part of the heat when say, $\frac{3}{4}$ or $\frac{4}{5}$ of the cupola was empty, the flow of air was much more rapid, and the demand for oxygen much less.

I think the whole test presents some very pretty questions and answers, and as I have never seen similar tests, I trust it will meet with careful consideration from the members of the Society, in the hope it will lead to other and more careful tests, where the fuel and iron will be carefully weighed, volume and

pressure of air observed, and nature of the escaping gases for C_1O_1 and C_1O_2 tested, and in the still more important hope that the results thus obtained will be placed in our contribution box.

In discussing that part of the paper relating to forge fans I would suggest that 4 ounces is, or should be, unusual. Consider, as solid coal weighs only .6 of an ounce per cubic inch with a blast of 4 ounces in the fire, we must tie the coal down to hold it in place. Is it any better engineering to run a blower to 4 ounces blast and discharge through reduced tuyerage until we get a practical blast of 1 ounce, than it is to carry 100 pounds pressure upon our boilers and throttle the steam pipe until we get 25 pounds in the cylinder?

I think the idea expressed in his paper is good; but his assumption of data seems to me to be excessive, and a reduction in the blast pressure could be advantageously made, even for extraordinary forge fires such as ship, smith, and, possibly, flange fires. I think it good practice to so design the conveying air pipe that the frictional losses will not exceed $\frac{1}{2}$ ounce per square inch in the total length, no matter how long. With a properly selected fan and ample tuyerage, 2 ounces will probably be ample, and the substitution of these figures in Mr. Sangster's formula will be fairly reliable, with the error on the side of safety.

Mr. Sangster's remarks in re-smoke exhausters are very apt, and, what is a safe approximation, is more a matter of opinion than an engineering question. Evidently he desires to remove not only the smoke and gases from the fires, but do some ventilating of the shop as well. If he will reduce his exhausting suction from $\frac{3}{4}$ ounce to $\frac{1}{2}$ ounce or less, without reducing his volume, he can reduce his power and still be on the side of safety.

The theoretical part of his paper, I hope, will receive consideration from other members of the Society.

*Mr. Sangster.**—I am glad to have Mr. Snell's discussion and data, and hope that those of our members who have electrically driven fans and can thus easily measure the horse-power required by their cupolas and forges, will bring before the Society the results of their experiences.

Regarding the question of blast pressures for forges, it would have been better to say: "The usual maximum pressure of blast

* Author's closure, under the Rules.

is 4 ounces per square inch." For such rough assumptions, however, it is well to keep on the outside.

By adding slightly to the amount of air handled and power required by the cupola blowers and smoke exhausters, we can summarize the results into handy approximate formulæ as follows:

Cupola blowers: Horse-power = $\frac{1}{8}$ tons of iron melted per hour times the pressure of blast in ounces per square inch.

Forge blowers: Horse-power = number of forges divided by 4.

Forge smoke exhauster: Horse-power = number of forges divided by 5.

No. 881.*

POWER AND LIGHT FOR THE MACHINE SHOP AND FOUNDRY.

FORREST R. JONES, WORCESTER, MASS.

(Member of the Society.)

ALTHOUGH there have been several papers read before this Society upon electric power transmission for the machine shop and foundry, and the discussions thereon have been extensive and interesting, the question is of such growing importance that it is believed that more attention can be very advantageously given to it. Some of the papers and discussions have taken up lighting in connection with power transmission, but this has not generally been the case. The two are frequently so closely connected, however, that one often cannot be fully studied without the other. The writer has recently had occasion to investigate the plants of two concerns with regard to electric power transmission and light. In one of these, the floor space over which light and power are required is about 7 acres; in the other, about 4 acres. The arrangement of the floor space is radically different in the two cases. In the first, there are several buildings entirely separate and at some distance from each other, and the floor space is nearly all upon the first floor, there being a small amount upon the second floor, and next to nothing on the third floor. In the second, the floor space is nearly all in an L-shaped building, partly of four stories and partly of three, and, in addition to this, a small two-story structure setting close to the other building within the inner angle of the L.

The output of the establishments is in a way similar, both producing iron machinery chiefly. In the smaller establishment, the product is much lighter in weight than in the larger. The operating machinery in the two plants is quite similar, the lighter machinery is about the same in each, but the larger has a considerable amount of heavy machinery which has no coun-

* Presented at the New York meeting, December, 1900, of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

terpart in the smaller. Both plants were examined to see what requirements would have to be fulfilled by an electric system, or systems, for power transmission and lighting. The first examination was made with a view to determining whether one or more kinds of current (of the direct, single-phase alternating, or polyphase class) would be desirable. In both cases the same conclusion was reached, namely, that the most feasible way to meet all requirements would be to adopt either one or more systems of electric circuits, the current to be of the same kind in each system if more than one were used, such that any electrical apparatus to be used in the plant, when placed in the location fixed for it, could be individually and conveniently attached to the electric circuit at a near point and operated by current therefrom in a manner suitable to the requirements of the service which the apparatus was designed to perform and the limitations of the service for the particular locality, the latter to allow for taking into account the fact that, at some places, a motor must run with a speed varying but slightly from uniformity, while at other places, and for other services, considerable variation of speed might not be objectionable; also, that while the electric light might, in some places, be required to operate with a uniform brilliancy and absence of fluctuation, as in an office or drafting room, there might be other places to illuminate, such as the foundry, casting-cleaning room, or an emery wheel, where a very considerable variation in its brilliancy would not impair its usefulness.

The selection of a single system from which all apparatus might be operated was based upon the conviction that, for machine shop and factory purposes, it is exceedingly desirable to be able to interchange similar apparatus and to place any piece of apparatus anywhere upon the system, thus obtaining the maximum flexibility and greatest facility for operating portable machine tools at any point, and also to allow for alterations and extensions of the works. The study of the requirements of every form of apparatus which might be brought into use and demand current from the system was naturally necessary in order to decide whether direct current, single-phase alternating, or polyphase, should be used.

The oldest of machine tools, the lathe, was taken up first, and since in both establishments it was deemed advisable to have some lathes driven individually by variable speed motors

governed by hand controllers, and that the variation of speed should cover, by small steps, a considerable range, the only thing which seemed satisfactory for this purpose in the present state of speed control for different types of electric machinery was the direct current. And, in order that the range of controlled speed variation might be as great as possible, the multiple voltage system appeared to be advisable, even though the speed regulations were to be made, for a given supply circuit voltage, partly or entirely by rheostatic control of the current in the magnet coils of the motor.

Other machines of a nature in a way similar to the lathe, so far as their driving is concerned, among which may be included the boring mill, drill press, shaper, slotter, gear cutter, and screw machine, can be operated satisfactorily under conditions of speed variation similar to those which answer for the lathe.

The planer, whose reciprocating motion requires the reversal of nearly every part of its machinery, presents a problem which is not yet satisfactorily solved for electric driving by a direct-connected motor. Planers, some of them very large, have been driven by direct connected motors, but there is room for much improvement in the method. The nearest solution which has been reached is to drive its countershaft in one direction continuously, just as it might be driven from a line shaft, and effect the reversals of the machine in the ordinary method common to mechanical driving, The ability to secure different cutting with maximum return speeds for machines of this type is unquestionably desirable when working upon different kinds of materials, or for taking heavy and light cuts. Different speeds can be obtained readily with many types of direct-current motors by rheostatic control of the field magnet current and, therefore, this feature needs no further attention than already given to the lathe.

Nearly all electric hoists and cranes are now operated by constant-pressure, direct-current motors. They seem to be at least as satisfactory as those driven by any other type of current.

Constant-potential, direct-current arc lamps have long shown themselves efficient, durable, and otherwise satisfactory. They can be operated individually and economically at any pressure between 100 and 125 volts, even though the pressure fluctuates considerably. (It is not intended that these are the limiting pressures of satisfactory service.) The lamp is, of course, more economical at its rated pressure without any of its rheostatic

resistance in circuit. Incandescent lamps have long been operated at from 100 to 110 volts with perfect satisfaction.

Motors for electric cranes and for general power purposes about the machine shop can be operated satisfactorily at any of the ordinary pressures for running motors, but it was not thought advisable, especially in connection with the conditions to be met in operating other apparatus, to give them a pressure greater than from 220 to 250 volts. The higher the voltage, within practical limits, the greater the economy of wire in the electrical circuit, of course. But, even leaving the requirements for other apparatus out of consideration, voltage as high as 500 is not desirable for the machine shop and foundry, for there is always a considerable degree of probability that employees will receive shocks by coming in contact with the wires or machinery. The writer's experience has given him sufficient respect for a 500-volt circuit to make him wish to keep others away from it.

On the whole, it was, therefore, concluded that 220 volts for the majority of motors, and 110 volts for arc and incandescent lamps, would be the most suitable. These voltages can be obtained, as is well known, by the three-wire system which has been so long in use.

In order to obtain information as to the amount of power required for driving different parts of the plant, numerous tests were made upon individual machines, groups of machines, sections of line shafting, cranes and elevators. Although so many data have already been published showing the power required to drive machine tools for iron working and wood working, it is believed that there are some points of sufficient value among those obtained in these tests to entitle them to attention. The data given below are of a nature not generally found in the reports which have been made upon electric driving, but present some rather unusual cases.

The power required to drive a couple of lathes, one of 48-inch and the other 36-inch swing, was taken when both were polishing hollow cylindrical columns, one 10 inches in diameter and the other 12 inches. In both cases the polishing laps gripped the work so tightly as to keep the driving belt of each lathe on the point of slipping. The speed was as high as could be safely used for machines of this size. To drive the two lathes together under these conditions, something over seven mechanical horse-powers delivered by the motor to the belt running from its

pulley were required. It can be seen that this is considerably more than is required for a lathe performing any of the operations common to machine construction in the ordinary shop. It may not equal the amount of power necessary for taking heavy cuts upon large steel shafts, heavy gun tubes and jackets, etc.; it does represent the power, however, which must be used as a basis to determine the size of a motor to drive a lathe which must do such work as demanded for these two. If a number of lathes for this class of work are to be grouped together, and there is a possibility, which is very probable, that several of them may have polishing under way at the same time, and therefore demand a maximum amount of power, the motor for driving them as a group must naturally have a capacity equal to the combined maximum demands of all of them, due allowance being made for its ability to stand overloading for a short period of time.

Although it is well known that the power required to drive a metal-working planer is generally greater on the return stroke than for the forward, or cutting stroke, and that, at the time of reversal, the power demanded is exceedingly greater than at any other time, the following data may not be out of place.

Two planers, one with 22-foot table and 120 inches between housings, and the other with 25-foot table and 72 inches between housings, were both driven by one motor belted to a jackshaft, which in turn drove the two countershafts of the planers. The following data were obtained:

120-INCH PLANER WITH 22-FOOT TABLE AND 72-INCH PLANER WITH 25-FOOT TABLE.

Both machines driven by one motor.
Jackshaft running in all cases.

	Amperes.	
230 Volts.	20	One countershaft.
	60	Average for 120″ planer on cutting stroke, light cut, and one countershaft.
	55	120″ planer reversing from return to cutting stroke.
	110	120″ planer reversing from cutting to return stroke.
	27	Both countershafts.
	240 to 250	Both planers reversing from cutting to return stroke.

Both machines were working upon rather heavy castings and taking comparatively light cuts at short strokes over bosses and parts of the castings where other members of the machines were to be attached. The power, therefore, is approximately that

which would be required to drive the machines without taking any cut, but carrying loads upon their tables. It may be noticed that the amount of power for reversing the 120-inch planer was about 1.8 times that for its average running at time when not reversing. When it happened that both machines reversed at the same time from the forward, or cutting, to the back, or return, stroke, the power required ran up to a very great amount, more than 60 mechanical horse-powers. This amount of power was not indicated by the instantaneous extreme throw of the ammeter needle, but was the reading at which the ammeter stood steadily for some seconds, a period long enough to make the demand distinctly felt by the engine and generator.

A planer with a 24-foot table and 60 inches between housings showed the following amount of power required:

60-INCH PLANER WITH 24-FOOT TABLE.

	Amperes.	
230 Volts.	7	Shafting only.
	8–9	Forward stroke without cut.
	10–15	Light portion of cut on rough casting, $\frac{1}{8}$ inch feed.
	15–20	One tool cutting cast iron $\frac{6}{16}$ inch deep × $\frac{1}{8}$ inch feed.
	20–25	One tool cutting cast iron $\frac{7}{16}$ inch deep × $\frac{1}{8}$ inch feed.
	20–25	Cutting $1\frac{1}{16}$ inch groove in cast iron with square nose tool; feed between $\frac{1}{32}$ inch and $\frac{3}{64}$ inch; groove not cored.
	35	Reversing from return to cutting stroke.
	45	Reversing from cutting to return stroke.

It may be noticed that the power required for reversing this machine, especially from the cutting to the higher speed return stroke, is nearly double that for the forward stroke when cutting.

A planer with a 40-foot table and 74 inches between housings gave the following data. The great power required for reversing from the cutting to the return stroke again stands out:

74-INCH PLANER WITH 40-FOOT TABLE.

Cutting speed, 20 feet per minute; two tools operating on cast iron; cut on each, $\frac{1}{4}$ inch deep, $\frac{1}{8}$ inch feed.

	Amperes.	
234 Volts.	22	Countershafting only.
	50	Considerable portion of the time while cutting.
	60	For some moments while cutting.
	35	Middle of return stroke.
	90	Reversing from return to cutting stroke.
	120	Reversing from cutting to return stroke.

Of the twenty-odd travelling cranes in one establishment, ten were tested for the power required to drive them. Of these ten, some were driven electrically and some mechanically. The majority of the electrical cranes were of the ordinary types designed for electric driving. One was a remodelled crane which had originally been driven mechanically by a square shaft running alongside the building parallel to the track. Some of the mechanically driven cranes were furnished power by a square shaft alongside the building and parallel to the track, and others by a flying rope running alongside the track. Obviously, in providing for the power to drive a crane it is necessary to know the maximum amount of power that it may demand for a period of time great enough to make the demand appreciably felt by the generating plant. In this respect the following data, obtained from three electric travelling cranes of 30 tons capacity each, all traversing the same track above the foundry floor, show how great may be the demand, for an appreciable period of time, by some one of the cranes, and, with perfect possibility, by all of them at the same instant.

Each of the 30-ton cranes was equipped with four motors: 25 horse-power for bridge travel; 8 horse-power for trolley travel; 25 horse-power for the main hoist; and 16 horse-power for the auxiliary hoist.

30-TON ELECTRIC TRAVELLING CRANE NO. 1.

Pressure, 240 volts when crane was taking no current.

Amperes.	
125	Bridge starting, no load.
50	Bridge travelling uniformly, 350 feet per minute, no load.
33 to 40	Lowering, no load.
105	Starting to hoist, no load.
36	Hoisting uniformly, no load.
145	Bridge starting, 20-ton load.
50	Bridge moving uniformly, 240 feet per minute, 20-ton load.
95	Hoisting 20 tons uniformly at 10 feet per minute.
310, 200, 150	General maneuvering, 20-ton load.

30-TON ELECTRIC TRAVELLING CRANE NO. 2.

	Amperes.	
240 Volts.	110	Bridge starting, no load.
	65	Bridge travelling uniformly, 450 feet per minute, no load.
	15	Trolley starting, no load.
	13	Trolley moving uniformly, no load.
	36 to 50	Lowering, no load.
	130 to 150	General maneuvering, no load.
	90	Bridge starting, 20-ton load.
	50	Bridge travelling uniformly, 20-ton load.
	145	Hoisting, rapid start, 20-ton load.
	115	Starting to hoist, reading for 8 seconds, 20-ton load.
	95	Hoisting 20 tons uniformly at 10 feet per minute.
	260	Bridge and trolley starting, reading for a few seconds, 20-ton load.

30-TON ELECTRIC TRAVELLING CRANE NO. 3.

	Amperes.	
240 Volts.	90	Bridge starting, no load.
	50	Bridge travelling uniformly, 535 feet per minute, no load.
	38	Lowering uniformly, no load.
	40 to 45	Hoisting uniformly, no load.
	150	Bridge and trolley starting, 20-ton load.
	30	Trolley at uniform speed, 20-ton load.
	84	Hoisting uniformly at 11 feet per minute, 20-ton load.
	240	Bridge and trolley maneuvering, reading for three seconds, 20-ton load.
	320, 250, 200, 230, 180	General maneuvering, 20-ton load.

It can be seen, by examining the data obtained from these 30-ton cranes, that, when all the motions on one were in operation simultaneously, and when two or more of the movements were started at about the same instant, the demand made for power during this general maneuvering was very great indeed. The readings given for such general maneuvering for two of the cranes when carrying a load of 20 tons each, the reading running as high as 320 amperes in one case and 310 in the other, represent demands for current during periods of from five to six seconds duration, as shown by the steady reading of the needle of a dead-beat ammeter. It not infrequently happens that such a condition comes about in every-day practice. That two or more of these cranes did, when in regular service, make very heavy demands for current at the same instant, was clearly

shown by watching the ammeter at the switchboard of the generator supplying current to the three cranes only. Although this generator had sufficient capacity to operate several 30-ton cranes under what might be called average load, and the magnetic circuit breaker for the generator was set considerably above the steady-load capacity of the generator, it was not an infrequent occurrence for the circuit breaker to open up the circuit on account of the great momentary demands made for power by the cranes.

Tests upon a 15-ton electric crane, two 5-ton electric cranes, a 15-ton flying-rope crane, a 15-ton square-shaft crane, and a 15-ton square-shaft crane remodelled to be driven direct by an electric motor, all showed similar heavy momentary demands for current under general maneuvering.

A somewhat surprising condition was found in one of the elevators, which, during the regular operation of the shop, was driven mechanically from the line shaft by means of a worm and worm-wheel connected to a winding-drum for the elevator cable. The elevator was of comparatively small capacity, and should not ordinarily require probably more than 5 horse-powers to drive it. But, apparently on account of some fault of the worm and worm-wheel mechanism, the very excessive amounts of power shown in the data given for this elevator were sometimes required.

ELEVATOR OPERATED BY WORM AND WORM-WHEEL.

Mechanical Horse-powers.		
Going Up.	Coming Down.	
19.2	10.4	No load.
16.5 to 21.8	....	No load.
....	.1	After running some time.
2.5	....	One man on.
....	.1	Countershafting only.
7.8	....	2-ton load, estimated.
7.3	....	2-ton load, estimated.

When well oiled, 15 amperes were at one time required to lower the cage without load; but for the following trip, immediately after, 60 amperes were required to lower without load. The next trip down took only 15 amperes. The same variation of power occurred throughout the test.

The worm-and-wheel mechanism appeared to be in proper condition, however, as far as could be seen by outside inspection; it was well lubricated by a bath of oil and flake-graphite, in which the worm ran. Here seems to be a lesson in the use

of the worm and worm-wheel mechanism setting forth the fact that care should be taken in its adjustment, and to see that the rubbing surfaces of the worm and wheel are kept in proper condition.

Two fans, used in connection with steam coils and hot-air pipes for heating the buildings, took the following amounts of power to drive them. They were both of the radial-blade, fan-wheel type (the blades arranged as on the paddles of a side-wheel steamboat). The casing of the larger measured 108 inches in diameter by 60 inches wide, the latter measurement taken parallel to the fan shaft. There were two tangential discharge openings in the case: one at the top, 24 by 60 inches, and another at the bottom, 54 by 28 inches; the larger dimensions in both openings were parallel to the fan shaft. The rotating part of the smaller fan measured 60 inches in diameter by 28 inches wide. It had a single outlet, 29 by 31 inches. Each fan had been installed by its manufacturer in connection with the other parts of the heating system. The larger one was not brought up to its rated speed because the power required to drive it was much more than anticipated when a motor of 20 horse-power capacity was belted to it. The slipping of the belt was the real limiting cause for not applying more power with the 20 horse-power motor. There was not time to substitute a larger motor or another belt:

108 × 60-INCH FAN FOR HEATING.

Mechanical Horse-powers.	Revolutions per Minute.
20.6	160
23.6	180

60 × 28-INCH FAN FOR HEATING.

Mechanical Horse-powers.	Revolutions per Minute.
.8	120
1.2	176
4.8	275
11.4	360
12.5	370

That more complete data might have been taken in the above tests is fully realized by the writer, but at the time of obtaining them there was no thought of making them public. The work was done only to obtain an idea of the power required to drive, so that the size of motor might be specified.

By examination of the data given above, it may be seen that the constantly recurring and great momentary demands for power made by cranes and hoists would necessarily affect the pressure in the wires carrying current to them from the switchboard in the power house. Hence the circuit feeding the crane and elevator motors would not be also suitable for furnishing current to motors which require to be run at even a fairly constant speed, or even hardly for incandescent lights in places where a steady illumination is not essential. It would be difficult to find constant-voltage arc lights which would operate with even a fair degree of satisfaction at the points of greatest variation of pressure in the circuit. It, therefore, becomes necessary to have what might be called a "crane circuit" for at least the majority of the larger cranes in an establishment of the proportions of those mentioned earlier in this paper.

The incandescent lights for use in offices, drafting rooms, and possibly some parts of the shop itself, as the tool room, and where the small and more accurate parts are manufactured, must have a pressure in the circuit leading to them which, at least, does not fluctuate rapidly, even though it may be allowable for it to vary slowly to a slight extent. A "lighting circuit," primarily intended for incandescent lighting, therefore, also becomes a necessity.

Such machinery as lathes, drill presses, shapers, milling machines, slotters, and gear cutters do not ordinarily need to be driven at a speed that is even nearly uniform. Variation of speed on each side of the normal is allowable to a considerable extent in many cases, provided the variation is not a jerky one, such as often comes on line shafting used to drive heavy planers. A third circuit, primarily intended for driving machinery of this class, needs to be installed. This may be conveniently referred to as a "machine-tool circuit."

Whether an iron-working planer may be placed upon the machine-tool circuit depends largely upon the size of the planer. The heavier machines, on account of the great momentary demands they frequently make for power, would be apt to produce sudden and considerable variations of pressure in the machine-tool circuit. Better general operation of the entire plant can be obtained by placing them on the crane circuit. The smaller planers can safely be placed upon the machine-tool circuit, thus obtaining more uniform motor speed for driving

them, while not materially affecting the pressure in the latter circuit.

The pressure on the machine-tool circuit would remain constant enough to operate constant-pressure arc lamps with perfect satisfaction. Such lamps, therefore, may be placed anywhere upon either the machine-tool circuit or the lighting circuit, and possibly upon some parts of the crane circuit where the fluctuation of pressure is a minimum for that circuit. Incandescent lights can, of course, be placed upon any of the circuits. The pressure in the machine-tool circuit should be sufficiently constant to insure a brilliancy uniform enough for many places in which an incandescent lamp is put.

Certain classes of machine tools, of which the emery grinder for finishing reamers, mandrels, and accurately formed machine parts is a type, require a very constant speed for the production of well-made pieces. A jerky speed, as of a line shaft forming part of a system on which are heavy metal-working planers, causes the grinding wheel to cut deeply into the work in some places, thus making a well-finished product impossible. Power for light machines of this type may be taken from the lighting circuit without detriment to its constant pressure. Desk fans, and even larger ones, can also be connected to the lighting circuit without harm to its constant pressure.

On account of the great variation in the amount of power demanded by cranes and other classes of machinery, already mentioned, it was doubted whether all the circuits leading out through the works could be connected to the same 'bus bars in the power house without causing a fluctuation of pressure great enough at the 'bus bars to affect appreciably the constant brilliancy of the incandescent lamps placed in locations where the most steady light would be required. Just what would be the effect could not be predetermined. For this reason it was decided that the switchboard should be so made and the generating machinery so divided into units that, if the amount of fluctuation caused in the incandescent lights should be too great when feeding all circuits from the same 'bus bars, the crane and heavy-planer circuit could be thrown on to one generator, and the other machinery and lights fed by another generator. If, as was hardly supposed would be the case even with this arrangement, the incandescent lamps should not burn steadily enough, there would still remain the expedient of a separate

generating unit for the lighting circuit. The supposition was that, even though such a separate lighting unit might be necessary at the times when the cranes would be performing their heaviest duty, which is while running off a heat in the foundry, there might be other considerable periods of time when the demands by the cranes would not be sufficient to affect the lights appreciably, even though all were operated from the same 'bus bars. Such being the case, the lighting unit would have to be operated a small part of the time.

It seemed advisable to install at least two generating units exactly alike, and to have one small unit which might be used for furnishing the current to run one or two machine tools, or even a small electric hoist or elevator, when there might be a demand for such service on account of making repairs, or operating some one or two machines on holidays, or in case of a breakdown. Such a unit to be driven independently of the main power-plant, so that, even though the fires might be dead under the boilers, this extra unit could be operated. A unit consisting of a small generator driven by a water wheel, or by a gas or gasoline engine, would answer such a purpose. Two large units, running in parallel, for carrying the bulk of the load, or separately for dividing it between them in case the cranes and heavy planers would have to be driven separately from the other machinery, would give a desirable division of the power units for night work and when operating only a part of the plant. This would give an opportunity for repairing the generating units without hindering the running of the entire establishment.

Direct-connected units were selected as most suitable. While it is not believed that great multiplicity of generating units is desirable, it is thought certainly better to have at least two main units for the reason already stated.

A motor-generator was decided upon as the best apparatus for balancing the two sides of the three-wire circuit. In a plant where the installment of electrical machinery for power transmission goes on gradually the motor-generator may be made of an ordinary commercial motor and a generator, directly connected together. When the demand upon them becomes too great for their capacity, they may be replaced by larger machines and used for motors in some part of the establishment. It was not thought that a storage battery would be as satisfactory for balancing the system as the motor-generator.

The question of individual driving or group driving of the machine tools naturally came up. The solution depended almost wholly upon the convenience of arranging the tools for group driving, or the necessity of driving some individually on account of the location each should occupy in order that it might perform its special functions to the best advantage. As to what would be the most efficient limit for the smallness of motors for driving did not once come up. And the writer has been led to believe, by close examination of these two plants and the more general observations of many others, that, except for very light machinery, there is seldom any need of considering which would be the most efficient method of driving, group or individual; or what would be the smallest size of motor to be used for groups, the limit of subdivision being based upon considerations of efficient power transmission. Convenience of operation and the methods of securing the greatest amount of output from operating machinery are of so much greater moment, in most cases, than economy of driving in pounds of coal saved that the latter sinks into insignificance in comparison with the former. Where it is desirable to have a machine driven at a variable speed of such a nature that it can be obtained only by a corresponding variation of speed in the source of its power, then, in the general case, it is undoubtedly better to drive that machine individually by a variable speed motor, whatever the amount of power required for driving it. On the contrary, if there is a number of machines whose speed regulation can be satisfactorily secured through the ordinary mechanical connection with a uniformly rotating shaft, and if they can be grouped together and still perform their functions to the best advantage, then unquestionably the best method of driving is to use, within the limits of convenient arrangement, as few motors as possible.

The installation of small hoists, suitable for serving machine tools when the work handled is generally too large for one man to put in place, is one of the improvements in the modern machine shop which has worked much benefit and saved much time. When the work to be lifted varies in weight from 75 to 500 pounds, it is believed that the pneumatic hoist is generally best for the purpose. To be of most service it should always be available; therefore, one hoist can serve only a small number of machines at most. This being the case, there is no objection to having it attached to the feeder-pipe line by a hose of only

sufficient length to allow it to reach the machines lying in its field of operation. The cheapness and simplicity of the pneumatic hoist, as compared with the electric or any other form suitable for the purpose, are so strongly in its favor that it seems to have no competitor in this particular field. The air compressor for serving such a hoist is probably best electrically driven when of not too great capacity, but if the size must be large, a steam compressor forming a unit in itself seems best, it being assumed that water-power is not available.

The conveying of materials and machinery from building to building and through the yards of a large establishment must needs be done, if done expeditiously, by some form of industrial railway. The form of locomotive most suitable for this purpose is not easy to decide upon. The horse hardly enters into consideration, and men are too expensive for the purpose. On account of the necessity of running through shops containing finished product and valuable machines, a steam locomotive cannot be used on account of the deleterious fumes thrown out, not to mention the fire risk. The compressed-air locomotive appears to have proved more expensive in operation than the electric for such purpose, and the choice seems to be guided toward the latter. Current can be furnished for the electric locomotive most conveniently and economically by the overhead trolley system outside of the buildings and wherever else trolley wires can be erected. In most places inside the buildings, however, the trolley cannot be used, so some other means must be obtained for furnishing current to the locomotive. There seem to be two methods that merit consideration, namely, by the storage battery and by the contact system of a shoe underneath the locomotive rubbing against contact points placed alongside or between the tracks. The writer is in doubt as to which would be the more suitable. The storage battery has the advantage that, with it, the locomotive can be run to any part of the track connected with the establishment, even though trolley wires have not been erected, and can be operated when the electrical circuits have no current in them and when the plant is otherwise shut down. The period of time during which the locomotive can be operated under these conditions is limited to the capacity of output of the storage battery, of course. The exorbitant price demanded for the storage cell makes the cost of installation heavy, and the fact that the battery itself is liable to

rapid deterioration in the hands of such persons as are generally put in charge of it in the machine shop is a point very strongly against it. The underneath-contact system has been successfully operated for years in some plants, and new and important improvements have recently been made in it. It is believed to be, so far as its practical operation is concerned, by far the most satisfactory system that can be used inside the buildings. While we have no positive information upon the cost, it is believed that the expense of installation where there is a great amount of track inside the buildings might be quite large. The electric locomotive of each of the above types could, of course, be satisfactorily operated on a 220-volt electric system.

While watching the operations of electric travelling cranes, frequently when in the cage with the operator, the writer has always been impressed with the need of fewer levers for controlling the different motions. In a travelling crane with a single hoist, there are three controllers, each with its individual lever; one for the motion of the bridge along the stationary track on which the entire crane runs, one for the traverse of the trolley across the bridge, and a third for hoisting and lowering a load. If the crane has an auxiliary hoist, which is very common in practice where two are needed, then a fourth controller and its lever are added. On account of the necessity of quickly grasping and moving one lever after another, the operator is apt to move them more quickly and further than is necessary, thus throwing on a sudden heavy current, which strains and racks the machinery. This is the usual occurrence when quick time must be made.

It would not be a difficult or expensive task to have, for a single-hoist travelling crane, one lever to control any one of the three motions, and another to control the remaining two motions. One lever could control the bridge travel and the other both the hoisting and trolley traverse, the hoisting by moving the lever in a vertical plane and the trolley traverse by moving it horizontally. A combination of these two motions of this lever would control both the hoist and traverse at the same instant.

For a crane having a main and an auxiliary hoist, each of two levers could control two motions. One could control the main hoist and traverse, and the other the auxiliary hoist and bridge travel. By such a method of two-lever control the saving of

time and machinery would amply repay the extra expenditure necessary for suitably arranged controller levers, the additional cost of which need not be very great.

Indicator cards were taken from the five engines furnishing power for the mechanical driving system of one of the plants. These cards were taken at the time when the load upon each engine was at the maximum value that it was found to reach during a period of half an hour to an hour. The aggregate indicated power for mechanical driving thus obtained amounted to something over 500 horse-power. Cards were taken from the same engines in order to find the power necessary to drive the line shafting, countershafts, jackshafts and all other apparatus which ordinarily ran when no operating machine or crane was at work. It was found that this frictional horse-power was considerably over one-third of the amount found by taking the maximum for each engine, as stated above, when operating the machinery. Cards taken covering a considerable period of time show that in each case the power required of the engine was much less as an average from morning till night than obtained for the maximum load. While no actual calculations were made to determine the ratio of the frictional horse-power to that for this average load, it was very clearly shown that the indicated horse-power of the engine for average load was only about twice that for friction. Each engine drove its own system independently of the other engines. Still other engines were used for generating currents for the electric cranes and a few electrically driven machines and sections of line shafting.

While the results of tests upon several electric motors convinced the writer that as high a degree of economy as is often set forth for such machinery could probably not be obtained in a commercial machine built to withstand heavy loads and rough service, he was certainly convinced that a great saving of the power wasted on friction in the mechanical transmission system could be saved by electric driving. It was found that electric motors, manufactured by well-known concerns who make the best of apparatus, required, for a 10 horse-power motor, about 1 electrical horse-power to run it without load, there being no belt upon the pulley, and when the only frictional resistance to be overcome was at the journals and brushes. The latter were adjusted to bear lightly against the commutator, which was smooth and otherwise in good condition. Under

the same conditions a 20 horse-power motor required about 1.5 horse-power to drive it light, and a 25 horse-power motor required at one time 1.75 horse-power, but later, after the commutator had become slightly roughened by heavy overloading, it took fully 2 horse-power to run it light. Several other motors, of sizes ranging from 7.5 horse-power to 50 horse-power, showed similar demands for power to run them light. The motors were the products of several different manufacturers. The instruments used for taking the readings of current and pressure were of the Weston portable type. One was calibrated at the Weston factory during the test, and the others compared with it.

On one motor of 20 horse-power capacity it was noticed that the speed kept gradually increasing for some time after starting, until it became 5 per cent. greater than at first, or more, although the line voltage and load remained constant, and no adjustment was made on any part of the motor or its attachments. The increase took place when the motor was completely left alone. After an hour or two the increase ceased, and the speed remained constant. The speeding up was probably due to weakening of the field magnets caused by the gradual heating of the field coils, and the reduction of field current by the increased resistance of the field circuit on account of its heating. Such an increase of speed was not noticed on other motors.

Although the writer has just stated what might, by mistake, be taken as objections offered by him to the use of direct-current machinery, and might give opportunity to set forth the great advantages of synchronous and induction motors, which, on account of the absence of commutators, and even of collector rings in the latter type, do away with all the frictional commutator resistance, and, in addition, afford the utmost simplicity of construction, he wishes nevertheless to affirm that he believes the direct-current machinery to be by far the most suitable for such cases as those in hand, although, on the other hand, he believes that there are many cases, especially when a uniform rate of speed is essential without speed variation governed by a controller between fixed limits, where alternating-current machinery is by far the most suitable. While we often hear of the faults and frailties of direct-current machinery, it must not be forgotten that the direct-current generator and motor were the pioneers in the field of the commercial applica-

tion of electricity to lighting and power transmission, and that the tales of woe, true of the early machines, have a tendency to cling unjustly to the more modern direct-current machinery, although it has been so improved as practically to free it from all the faults of its younger days, and to make it as reliable and durable as the steam-engine. Neither should it be forgotten that the alternating, and especially the polyphase, machine coming on at a later date had the advantage of all the knowledge gained through some years of costly experience with direct-current machinery, and therefore does not have hanging around it any of the disagreeable reminiscences that are apt to follow the latter.

One great advantage of electric-power transmission in the machine shop is that of having a means of furnishing power to portable machine tools, either large or small, at any part of the works where suitable circuits are run. It is such a strong point in favor of electrical transmission that it deserves being ever kept before the minds of those who have to do with machine shop and factory. The time that can be saved and the greater accuracy of work that can be secured upon many kinds of large machine members, by setting them upon a machined plane-surface floor with slots and holes for inserting bolts to clamp them down, and then bringing portable machine tools to them with the crane, railway, or truck, each to perform its own special operation, make this method of procedure worthy of consideration by the manufacturer and builder of heavy machinery. The heavy casting can be set upon a flat metallic floor, and made ready for the tools to operate upon it almost invariably more quickly than it can be set for any machine tool occupying a fixed location. If the casting requires the operations of several kinds of stationary machine tools, it must be set again and again, as many times as there are permanently located machines required to do the work. To set a portable machine tool with a plane-machined base upon a level iron floor and to bring it into position for working upon a casting also upon the floor occupy but a fraction of the time necessary for setting the casting in position for a stationary machine tool. Moreover, several portable machines may be brought into action upon one casting at the same time. This is seldom true of machines fixed in location.

The writer hopes to see, and believes he will see, in no great

period of time, many builders of heavy machinery doing their work in this manner.

Why carry a heavy machine member about the shop to this place and that, and waste time setting it again and again before different machine tools, when many of the tools can so easily and quickly be brought to the machine part and put to work upon it?

DISCUSSION.

Mr. F. V. Henshaw.—Mr. Jones's paper is a valuable addition to the general data on electric power in machine shops. In the various papers that have been read before this Society on the subject, the points chiefly dealt with have been economy of power and the advantages due to flexibility, convenience, absence of overhead countershafts, etc., resulting from the use of electricity. All these advantages have been amply demonstrated in practice, with the result that the use of electric power in machine shops and mills has increased enormously. The Pencoyd Iron Works, National Tube Works, and the Baldwin Locomotive Works are good illustrations of this. The Pencoyd Company has at the present time some 4,400 horse-power capacity in motors, and it may be interesting to know that their average load is under 600 horse-power.

In regard to general economy, I would quote the statement recently made at the Franklin Institute by Mr. Vauclain, to the effect that the use of electric power in the Baldwin Locomotive Works had resulted in a saving equivalent to some 20 per cent. on the pay-roll, and 40 per cent. in shop area for a given output.

I mention these few illustrations out of many, merely to indicate the present status of electric power in large works. There is, however, a branch of the subject which has been given scant treatment in the present and in previous papers, but which is of the greatest importance, and which embraces possibilities of economy vastly greater than could be effected by any saving in power. I refer to the operation of variable speed tools by individual motors.

Mr. Jones merely touches the surface of this question in his remarks relative to individual and group driving, where he states that "convenience of operation and the methods of securing the greatest amount of output from operating machinery are of so much greater moment in most cases than economy of driving in

pounds of coal saved, that the latter sinks into insignificance in comparison with the former." This statement is the text, however, of my argument; and the most interesting problem in the use of electric power now before us is to determine the best means of accomplishing, by means of the electric motor, all the results in speed regulation that are now obtained by mechanical means, and adding to their effectiveness enormously by increasing the rapidity and convenience with which these changes can be secured.

The ideal condition would be represented by a lathe, say, with its motive power contained within it so that it could be located entirely without regard to anything but the greatest economy of space and convenience, and so arranged that by "pressing a button" any cutting speed could be instantly obtained over the whole range, of say from 15 to 75 feet per minute with diameters of work varying in the ratio of 20 to 100. I believe the increased output of a shop equipped with such tools, particularly on a piece-work system, would be very great, and would amply repay the cost of the investment in the special machinery.

The main questions to be determined are, first: what is the best and cheapest method of obtaining this result, and second, in what cases, nature of work, sizes of tools, it will pay, and in what cases in will not.

I fear that hitherto the mechanical and electrical engineers have failed to get together sufficiently to understand each other on this subject, hence much vagueness and lack of results. It may therefore be of interest briefly to go over various practical methods of obtaining speed control in electric motors, together with their limitations. The three vital factors, of course, are:

(1) Horse-power required.
(2) Maximum range of speed.
(3) Relation between torque and speed.

Variable speed tools can be divided into two distinct classes. First: Tools in which the cutting speed is variable, but in which the torque is constant for a given cut and kind of material worked. The planer is an example of this class, and the conditions are such that changing the cutting speed simply increases or decreases the horse-power required in proportion to the speed. This is a comparatively easy condition to meet in an electric motor, as it is a very simple matter to increase the horse-power of the motor without loss of efficiency or inherent regulation,

providing this increase is due to increased speed without increased torque. The problem of the reverse in the planer is another question, and I would say that I think this can probably be settled satisfactorily by the use of either pneumatic or magnetic clutches. I hope to have some data from actual experience before long on the use of such devices.

The second class includes tools like lathes or boring mills, in which not only must the cutting speeds vary over a great range, but also over various diameters of work, and it is evident that other things being equal, the torque on the motor will vary directly with the diameter of the work, and the motor speed will vary inversely as this diameter. This makes a most difficult condition for the economic-speed control of an electric motor, as it requires from the motor an increasing torque with a decreasing speed, which is, of course, equivalent to increasing the horse-power by increasing the torque instead of the speed, a condition which is precisely the reverse of that alluded to in the case of the planer.

Now as to how to accomplish the results named above, consider the following facts.

The speed of a direct currect electric motor can be varied:

(1) By resistance in its field circuit over a maximum range of about 100 per cent., or 1 to 2, with high efficiency, with practically unlimited steps, and by a very simple device. On the other hand, the motor must be relatively large for its output, and the range of speed, as will be seen, is comparatively small.

(2) By resistance in its armature over a range practically from zero to full speed, by means of simple apparatus, and with a motor relatively small for its output. With this method the efficiency is very low at the lower speeds. For instance, at half speed there is just as much power wasted in the resistances as is used in the motor, and at lower speeds there is correspondingly greater loss. What is even more serious than the loss of economy is the fact that the self-regulating power of the motor is entirely destroyed at the lower speeds, so that in operating machine tools the speed of the tool at the beginning and end of the cut would increase greatly above the speed while cutting. Probably a reduction in speed of 50 per cent. by this method is as much as could be satisfactorily used in most machine tool work. This is not enough to be of advantage by itself, but is extremely useful in obtaining the small steps in combination with other methods of obtaining the large steps, as will be explained hereafter.

(3) By special construction of motor having two commutators and two windings, three speeds can be obtained over wide range with high economy, good regulation, and no resistances. The variations between these three steps must be obtained by methods 1 and 2 or both. Such a motor as this can be driven by a standard 2-wire current supply. The disadvantages, however, are that the motor is relatively very large and expensive for its output, and being extremely special has the disadvantage incident to anything not a standard article. Also, where the range is large—that is, 4 to 1 and over—the gaps to be filled in between the three speeds represent a large range of themselves, and may go beyond the limits which can be economically and satisfactorily filled up by methods 1 and 2.

(4) By what is called the Ward Leonard system, requiring two machines of equal size and an external source of power. With this method a range of from zero to full speed with almost unlimited steps can be obtained. This is practically a perfect method of speed control, and leaves nothing to be desired; but the great first cost and the multiplicity of machines to care for have made it impractical except for use in special cases, where fine speed adjustment and convenience of manipulation are so valuable as to outweigh the disadvantages.

(5) By a multiple voltage system, any desired range of speed may be obtained with high economy and with perfectly standard motors relatively small for their output. The only disadvantages of this sytem lie in the fact that it is necessary to run at least four wires to the motors and to use a special machine for splitting up the voltage of the circuit. The system is extremely simple, and consists in distributing current to the motors at several different voltages, the ratios of the voltages being the same as the ratios of the speeds it is desired to obtain. I might describe it by stating that in the case of a machine tool we could have one voltage corresponding to each step of a cone pulley. By the use of four wires we can obtain six speeds over any range required in practice, and the intervals between these six speeds can be obtained efficiently and easily by either of the methods 1 and 2 if desired. The total number of speed variations obtainable is practically without limit, a very large number of speeds merely resulting in an increase in the size of the motor regulator.

The various voltages might be obtained by having one dynamo for each voltage. A better method for general service is to use

one or more standard dynamos, as the case may be, generating current at 250 volts. A balancing transformer is connected into the main-supply circuit, consisting of three or more small machines mounted on one base and direct-connected. These machines are so wound that they split up the voltage of the main generator in the required ratios. Wires from this balancing transformer and from the main line are then run to all motors which operate variable speed tools. All the rest of the machinery—namely, all machines such as grinders, very small lathes, sharpers, etc., fans, blowers and pumps, and other machinery which can be operated by constant-speed motors, travelling cranes—as well as all lights, would be supplied from the 250-volt main.

The balancing motor-dynamo is a very simple machine requiring scarcely any attention, and would not be of excessive size and cost. It has simply to be large enough to balance the unequal distribution of the speeds and power among the various tools. I will not elaborate this further, as I have already made this discussion rather long.

The above methods of speed control refer to direct-current motors, which I consider preferable for general machine shop work. The arguments on the question of direct versus alternating-current power distribution are too lengthy to enter into at this time. I will add, however, that with alternating-current motors, method 1, which is of extreme value, cannot be used. There is a method for regulating alternating-current motors analogous to method 3; namely, by changing the connections of the stationary winding.

There is also a method analogous to method 5, which consists in a multiple wire system supplying current at different frequencies to the motors. Whether these or other methods of regulating alternating-current motors can be brought to the same state of perfection as the methods of regulating direct-current motors cannot yet be stated, but there are indications that they cannot, and, generally speaking, in the present state of the art, I think that the best engineering is to use alternating currents purely for long transmission and direct currents for distribution.

I believe that the problem I have emphasized can be successfully and economically solved by the multiple-voltage system here mentioned. It is already in use to a small extent, but is comparatively new, and exact information as to economical results obtainable is not yet available.

While I do not wish to be considered as one of the enthusiasts alluded to by Mr. Rockwood at Hartford in 1897, I do not hesitate to state my belief that the operation of variable-speed machine tools of the larger sizes by individual electric motors and without cone pulleys or change gears will be the common practice within two years at most.

As to the cases where it will not pay, I would say that I think such will embrace only tools of a very small size and shops where there is so little work done that the tools are idle a great part of the time.

I would like to bring one further point forward; namely, that in working out the problem as here outlined it is absolutely necessary to get data as to actual power required to drive machine tools, in order to secure economy in cost of equipment. In my experience, there are comparatively few machine-tool makers or users who know accurately how much power their tools require. Just at this time the problem is also complicated by the introduction of new tool steels which permit an enormous increase in cutting speed. As an illustration of the effect of this on the power system, I would compare Mr. Jones's results (given on page 371) with some tests I obtained using such tool steel on a 10-foot by 30-foot planer, working extremely hard steel with one tool cutting $1\frac{1}{8}$ inches deep; feed, 5.44 inches; speed, 15 feet per minute; average horse-power, $29\frac{1}{2}$; maximum horse-power, 32. Compare with Mr. Jones's results of about $15\frac{1}{2}$ horse-power average and $18\frac{3}{4}$ horse-power maximum, on a planer not much smaller, but cutting cast iron according to common practice. The planer in my case reversed at 26 feet per minute, and took a trifle less power to reverse than Mr. Jones's 74-inch planer, though there was a weight of at least 15 tons on the bed. The planer was driven by the $9\frac{1}{2}$-inch single belt, running about 1,500 feet a minute, and I fancy the makers allowed about 15 horse-power to drive the machine.

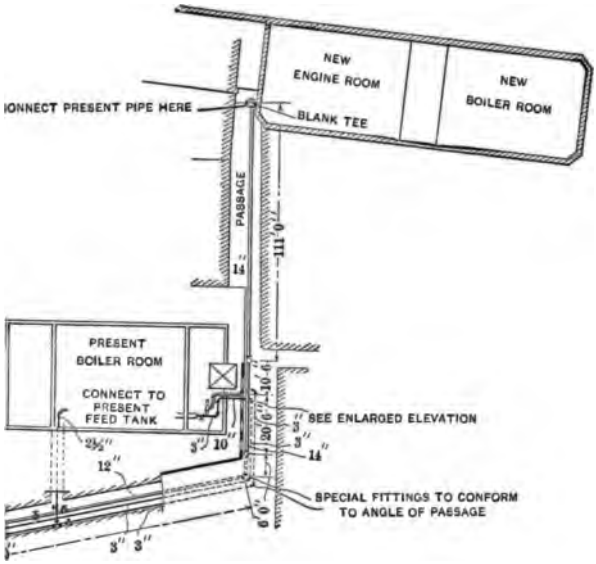
I must register an objection to Mr. Jones's statement on page 369 in regard to electric cranes, that direct-current motors are "at least" as satisfactory as those driven by "other type of current." The fact of the matter is that the direct-current series motor is as nearly perfect for the operation of cranes as anything can be, and at the present time there is no other type of electric motor that can compare with it for this service.

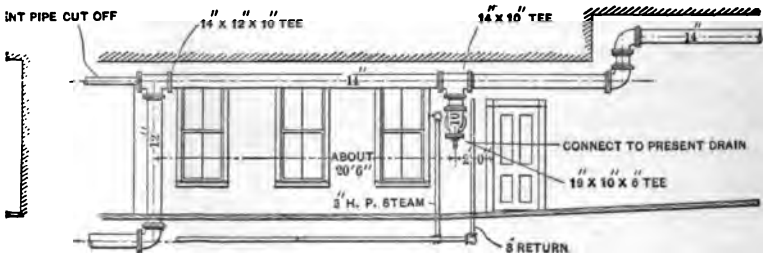
*Mr. Forrest R. Jones.**—Since the four-wire system of electrical

* Author's closure, under the Rules.

distribution for obtaining multiple voltages has been mentioned in the discussion, it may be said that this was considered along with the other methods. One of the manufacturing establishments using the four-wire system and individual motors for the machine tools was examined at the time of laying out the plans. But, as stated in the body of the paper, it was decided better—principally on account of first cost—to adopt the three-wire system. If there should be a machine, or machines, in any part of the shops requiring a great range of speed by minute gradations, a motor generator made up of two separate machines coupled together mechanically, or a 2-commutator double-wound machine, could, of course, be installed near the machine tool and used to drive its motor by the Ward Leonard system or by splitting the voltage on one side of the three-wire system, so as to obtain more voltages to be used in connection with variation of field strength for securing the required speed control. For the ordinary large machine shop and foundry this is believed to be as satisfactory as, and far less expensive than, the installation of the complete four-wire system, even though, as would generally be the case, not more than two or three of the four wires are to be carried to many parts of the works.

As to motors for electric cranes and hoists, there are certainly types of alternating-polyphase-current motors which have been used for this purpose, and, although the writer has not seen them in operation, he has information, which he believes to be perfectly reliable, that they operate with very good success. Other things being equal, however, his selection would be the direct-current motor for this purpose.





SIDE VIEW

ELEVATIONS OF PIPING NEAR PRESENT BOILER ROOM

asons for placing it at an extreme end, and this is one reason y the plant is interesting. Exhaust steam of two or three unds pressure is carried 800 feet from the engine room to the firmary, and is perfectly effective in doing the heating.

One of the drawings here reproduced (Fig. 124) shows the pipe om one end to the other. At the engine room it receives xhaust steam, and, if it is insufficient, a make-up supply is ssed from the boilers through a reducing valve to the exhaust ipe. As it is necessary to provide against interruption of rvice by the failure of the reducing valve, there is a stop valve ch side of it, and a by-pass through which a supply can be ssed by hand regulation, the upper limits of pressure being termined by a safety valve. Near the infirmary a separator as been inserted in the pipe for the purpose of removing ater in order to avoid water-hammer in the infirmary. The ater collected by this separator, and all other condensations nd returns, are returned to the boiler house by pumps in duplicate.

The infirmary uses steam of moderately high pressure for sterilizing, and a 3-inch pipe is carried over to convey such steam. The opportunity of making this useful for duplicating the steam supply for heating was taken, and at the infirmary a branch from this is run to the low pressure pipe with proper valves, and reducing valve.

The floor level of the boiler and engine rooms is placed nine feet below the surface of the ground, and a coal pocket capable of containing about 100 tons of coal is provided below the ground level, the floor of the pocket being level with the other floors. This pocket is covered with steel beams with brick arches between. There are a number of openings in the roof of the pocket so that coal can be emptied directly from carts into the pocket. This reduces the labor of unloading and renders coal handling machinery unnecessary.

Coal is shoveled into iron cars which are rolled on a track directly in front of the boilers, a scale for weighing being inserted at one end of the boiler room. In one corner of the pocket there is a hydraulic plunger elevator for raising ashes.

It was necessary to employ vertical boilers in order to economize floor-space, and those used were designed by the firm of which I am a member, the object of the design being to permit

internal examination, and thus to convert guess work into knowledge as to their condition. Their general design and some of their details are presented in Figs. 125–131 herewith.

In order to render the combustion comparatively smokeless with bituminous coal, the crown sheets of the boilers are placed eight feet above the grates, and the result is remarkably good, smoke being rarely seen, and never but slightly.

As there is but little room between the boilers and the main steam pipe, each pipe from the boilers is taken out of the back and passes between boilers in order to obtain sufficient length for flexibility. Inspection of the plan of the boiler room (Fig. 132) will show that each of these pipes is very long, considering how near to the boilers the main steam-pipe is. This flexibility is quite important with vertical boilers, because a hot boiler is somewhat higher than a cold one.

There are two feed pipes to each boiler, one for the main feed and one for returns. By this means a disagreeable snapping of the pipes, which sometimes occurs where feeds of different temperatures are mixed, is avoided. The opportunity to make a cross connection from one feed-system to the other was made use of, so that there is a duplicate feed-system.

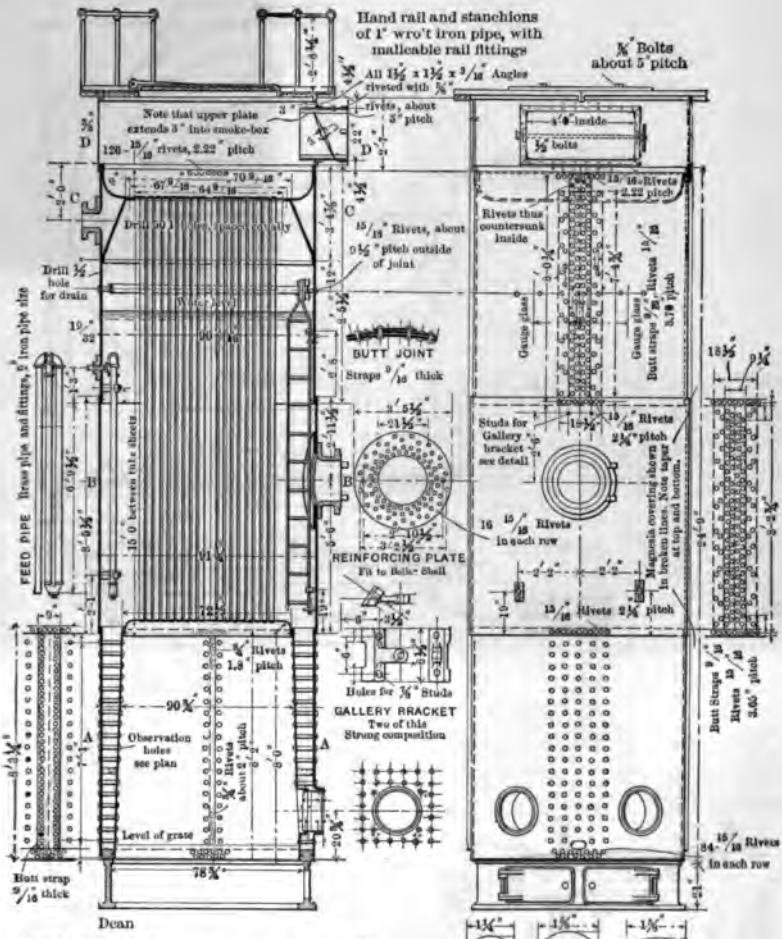
The blow-off pipes are taken to a tank which discharges to the sewer, but this pipe is also connected to the injector suction, so that the water in any boiler can be pumped into any other. This is an emergency provision which would be valuable if the city water-supply should be shut off, as sometimes occurs, whereby the water in a boiler out of service could be used.

One interesting feature of the station is the economizer. This is a Green, and is divided into two parts, either or the whole being capable of heating the feed for the boilers, or of heating water for domestic uses in the hospital.

As usual the smoke-flue arrangement is such that the economizer can be isolated and cleaned. The draft is controlled by an automatic damper regulator.

As room is scarce, and as the smoke-flues enter the chimney at a high level, the interior of the lower part of the chimney is used to contain a spiral stairway to connect the ground level and the floors.

In the pump room there is a duplex vertical Blake feed pump, a horizontal Deane duplex automatic return pump and receiver with outside packed plungers, a Wainwright feed water-heater,


Hand rail and stanchions of 1" wro't iron pipe, with malleable rail fittings
All 1½" x 1½" x 3/16" Angles riveted with ⅝" rivets, about 3" pitch
Note that upper plate extends 3" into smoke-box
126 15/16" rivets, 2.22" pitch
Drill ½" holes, diagonally
Drill ½" hole for drain
Water level
15/16" Rivets, about 9½" pitch outside of joint
BUTT JOINT
Straps 9/16" thick
FEED PIPE Brass pipe and fittings, 3" iron pipe size
15'0" between tube sheets
REINFORCING PLATE Fit to Boiler Shell
Holes for ⅝" Studs
GALLERY BRACKET Two of this Strong composition
Observation holes see plan
Level of grate
Butt strap 9/16" thick
Dean
⅝" Bolts about 5" pitch
All 1½" x 1½" x 3/16" Angles
⅝" bolts
Rivets thus countersunk inside
Gauge plate
Butt straps 9/16" thick
Studs for Gallery bracket see detail
16 15/16" Rivets in each row
Magnesia covering shown in broken lines. Note taper at top and bottom.
15/16" Rivets 2¼" pitch
Butt Straps 9/16" thick
Rivets 15/16" 2.65" pitch
84 15/16" Rivets in each row

Water-heating surface	1653 sq. ft.
Superheating "	576 " "
Total heating "	2229 " "
Grate surface "	33.18 " "
Area through tubes	5.71 " "
" " smoke-box nozzle	7.38 " "
Ratio, water heating to grate surface	49.8 to 1
" total " " " "	67.1 to 1
" grate area to tube area	5.81 to 1
" " " " smoke-box nozzle	4.53 to 1

RIVET AND SCREW-STAY HEADS

FIG. 125.

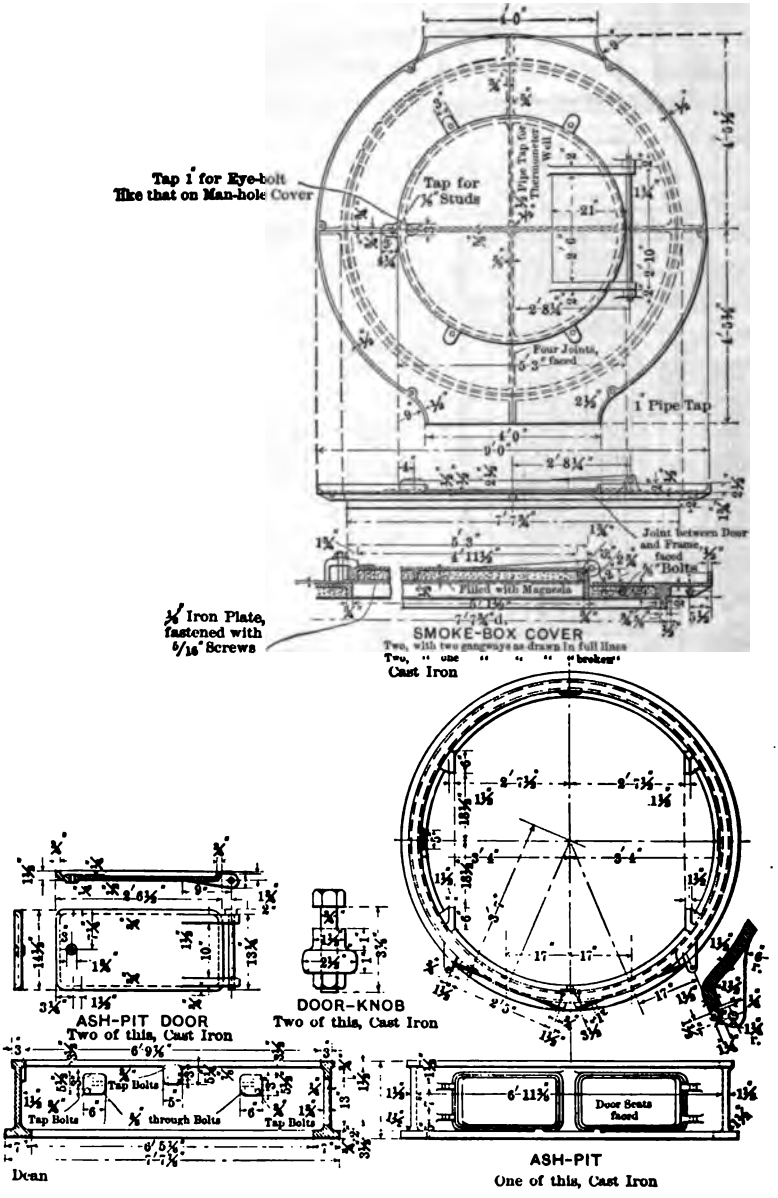

Tap 1" for Eye-bolt like that on Man-hole Cover
Tap for ⅜" Studs
Pipe Tap for Thermometer Well
Four Joints, 5'-3" faced
1 Pipe Tap
Joint between Door and Frame, faced
⅜" Bolts
Filled with Magnesia
⅛" Iron Plate, fastened with 5/16" Screws
SMOKE-BOX COVER
Two, with two gangways as drawn in full lines
Two, " one " " " broken
Cast Iron
ASH-PIT DOOR
Two of this, Cast Iron
DOOR-KNOB
Two of this, Cast Iron
Tap Bolts
⅝" through Bolts
Door Seats faced
ASH-PIT
One of this, Cast Iron
Dean

FIG. 127.

FIG. 128.

FIG. 129.

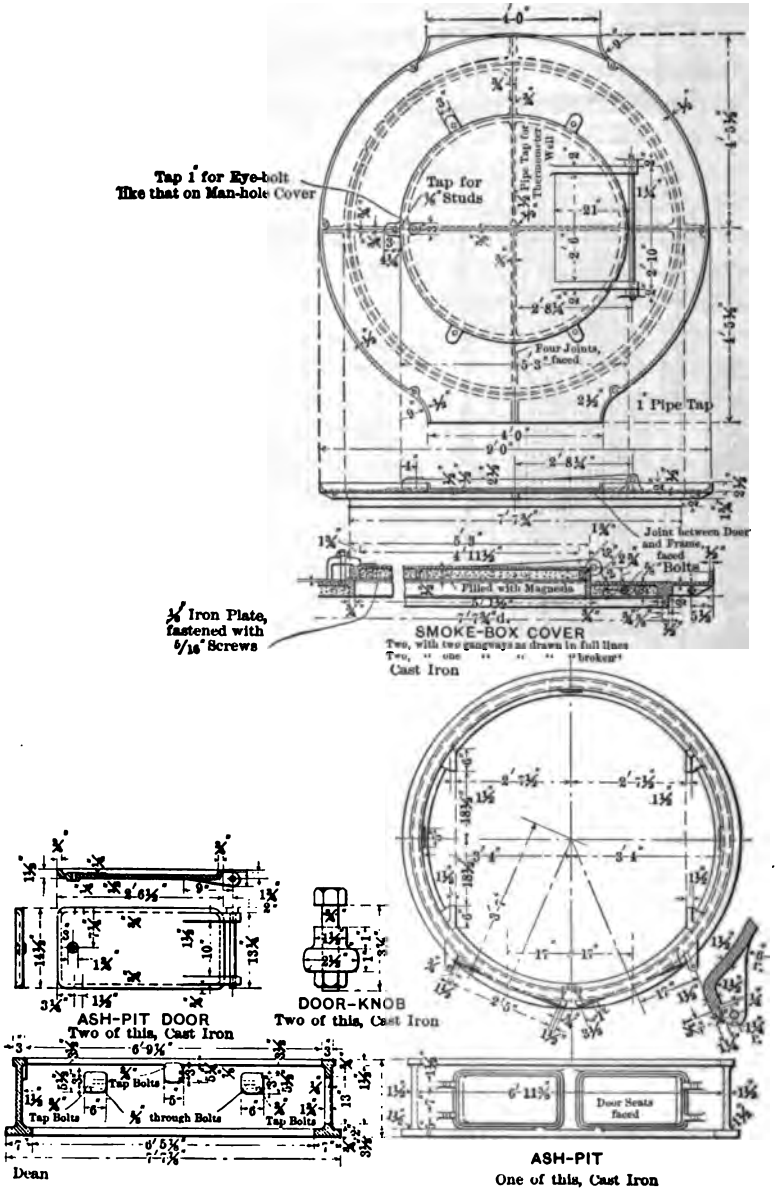

Tap 1" for Eye-bolt like that on Man-hole Cover
Tap for ¾" Studs
Pipe Tap for Thermometer Well
Four Joints, 5-8" faced
1 Pipe Tap
Joint between Door and Frame, faced
¾" Bolts
Filled with Magnesia
¼" Iron Plate, fastened with 5/16" Screws
SMOKE-BOX COVER
Two, with two gangways as drawn in full lines
Two, " one " " " " broken
Cast Iron
ASH-PIT DOOR
Two of this, Cast Iron
DOOR-KNOB
Two of this, Cast Iron
Tap Bolts
through Bolts
Door Seats faced
ASH-PIT
One of this, Cast Iron
Dean

FIG. 127.

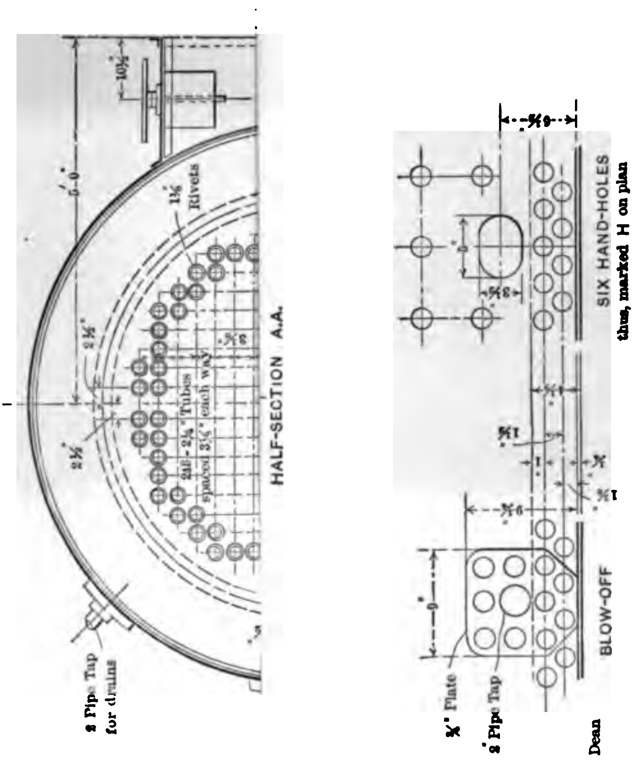


FIG. 128.

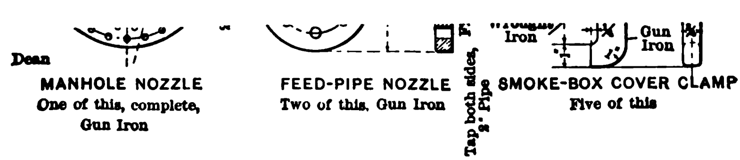
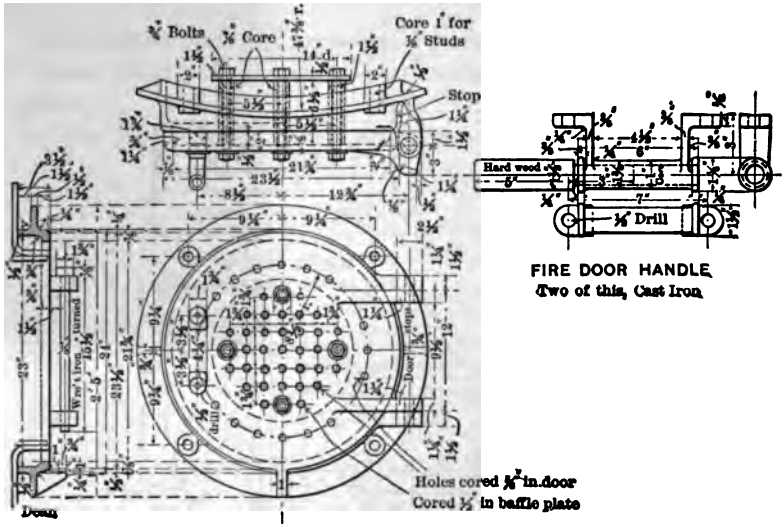


FIG. 129.

One of this, Cast Iron

FIG. 127.



FIRE DOOR HANDLE
Two of this, Cast Iron

FIRE DOOR
Two of this, Cast Iron
One right hand, one left hand

FIG. 128.

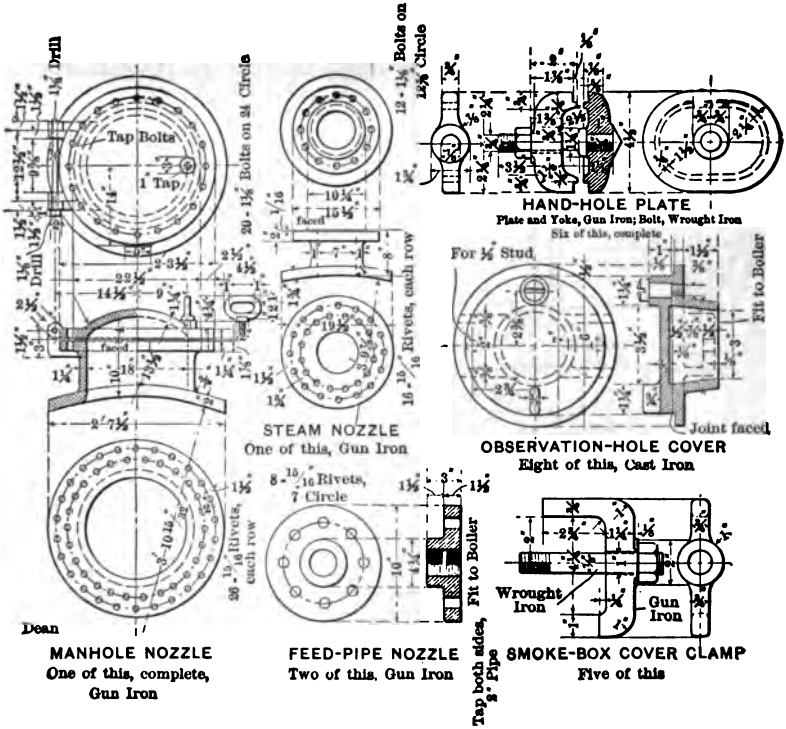
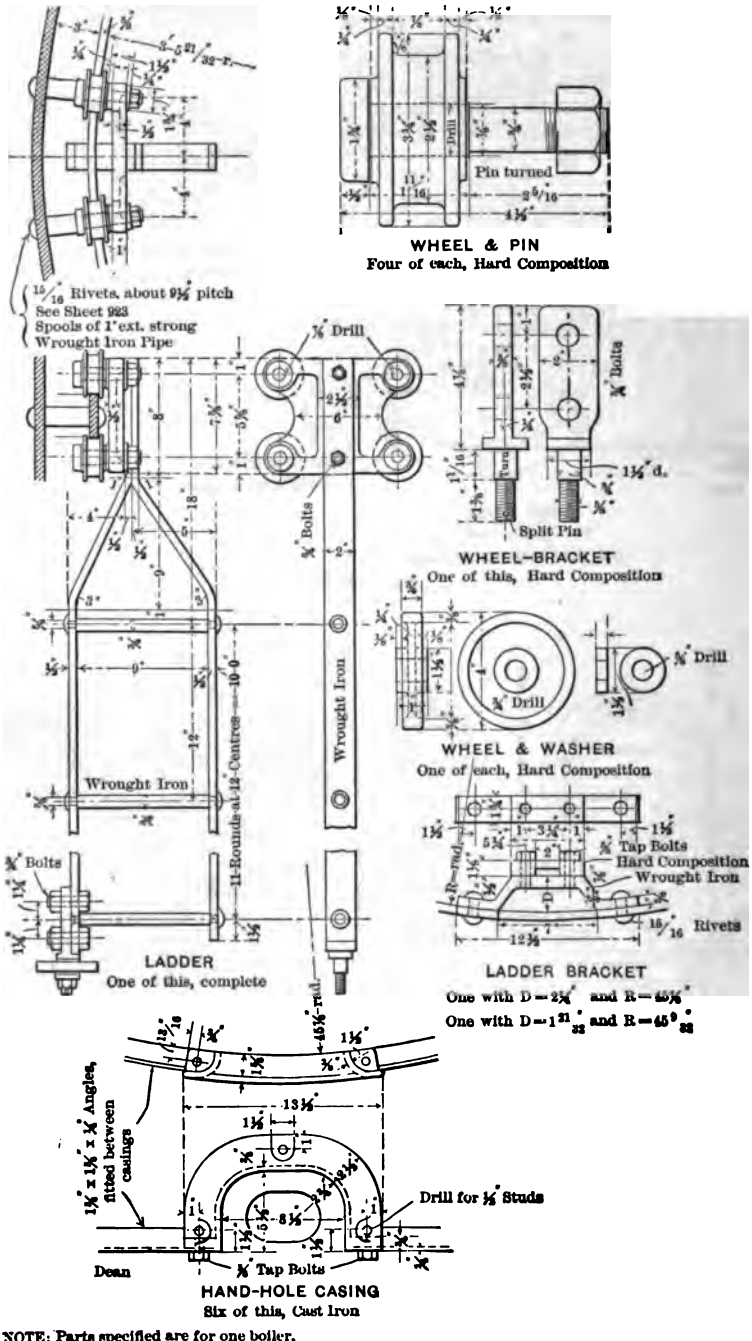


FIG. 129.

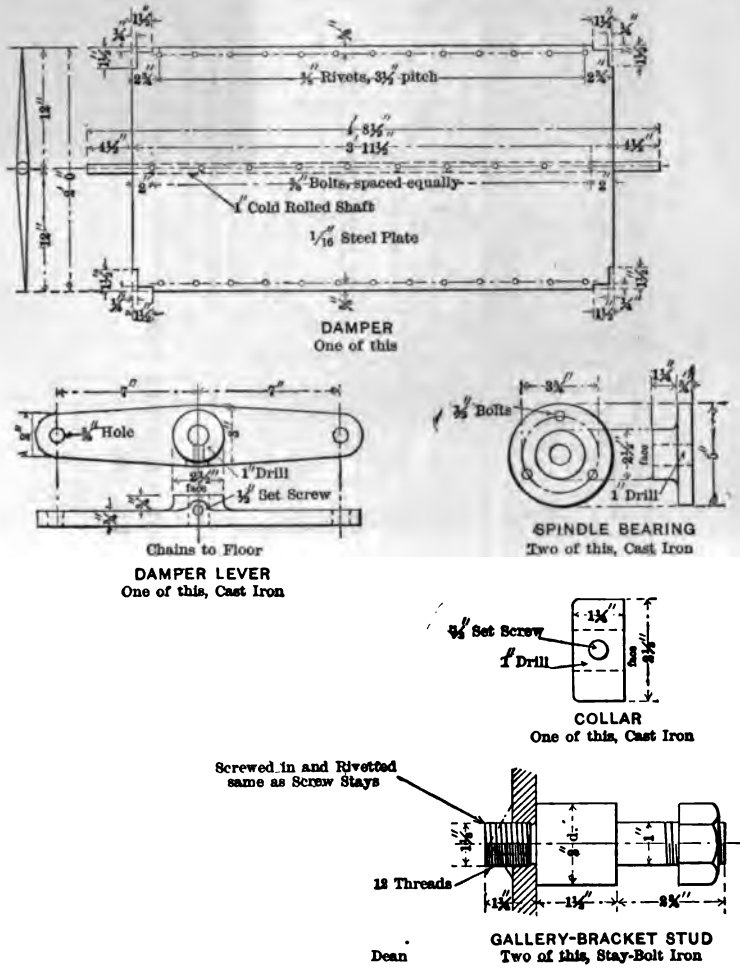


NOTE: Parts specified are for one boiler, except smoke-box cover, which see.

FIG. 130.

a Worthington hot-water meter, and various traps. Nearly all of these pieces of apparatus are arranged to be isolated for repairs.

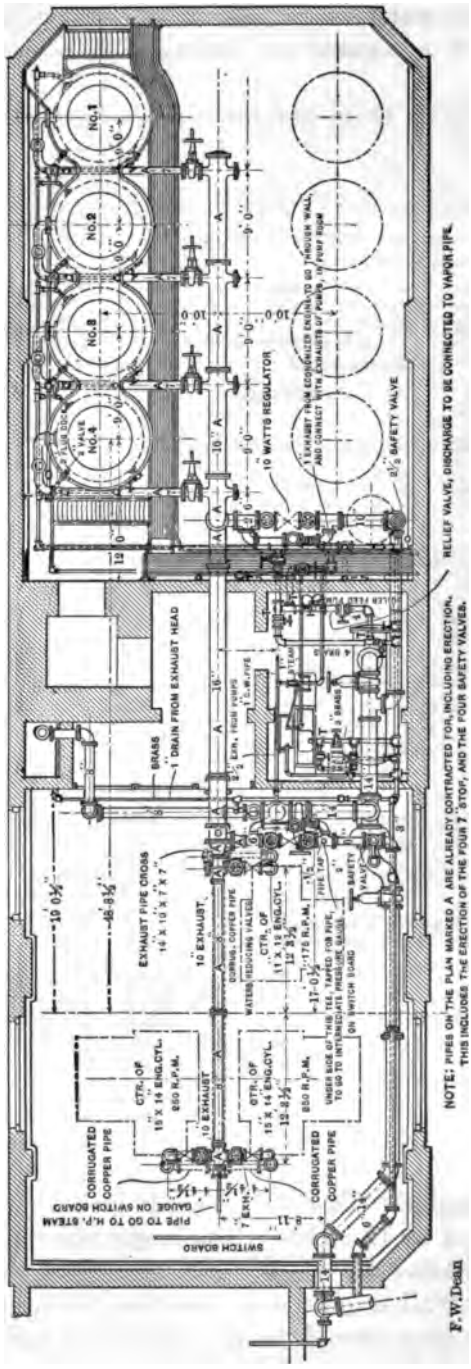
In the engine room there are three Ames horizontal simple



Dean

FIG. 131.

non-condensing engines. Two of them are 15 inches by 14 inches, and one 11 inches by 12 inches. The larger ones are directly connected to 100-kilowatts Walker generators, and the smaller to a 50-kilowatts Walker generator. Each of the larger engines and generators is large enough for the night load, and therefore



NOTE: PIPES ON THE PLAN MARKED A ARE ALREADY CONTRACTED FOR, INCLUDING ERECTION. THIS INCLUDES THE ERECTION OF THE FOUR 7" STOP, AND THE FOUR SAFETY VALVES.

POINTS MARKED T SHOW LOCATIONS OF EIGHT THERMOMETERS.

PLAN OF ENGINE AND BOILER ROOM

FIG. 132.

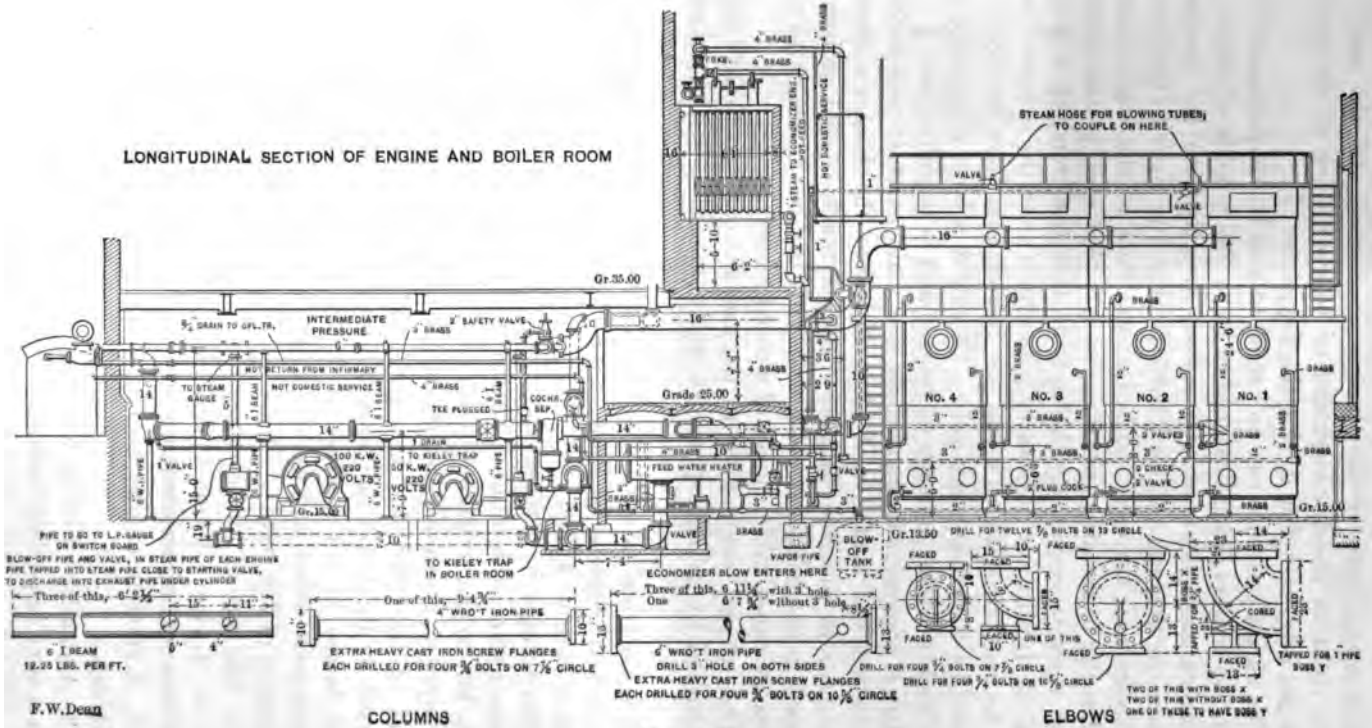

LONGITUDINAL SECTION OF ENGINE AND BOILER ROOM
STEAM HOSE FOR BLOWING TUBES, TO COUPLE ON HERE
INTERMEDIATE PRESSURE
TO KIELEY TRAP IN BOILER ROOM
ECONOMIZER BLOW ENTERS HERE
BLOW-OFF TANK
FEED WATER HEATER
NO. 4
NO. 3
NO. 2
NO. 1
PIPE TO GO TO L.P. GAUGE ON SWITCH BOARD
BLOW-OFF PIPE AND VALVE, IN STEAM PIPE OF EACH ENGINE PIPE TAPPED INTO STEAM PIPE CLOSE TO STARTING VALVE, TO DISCHARGE INTO EXHAUST PIPE UNDER CYLINDER
6" I BEAM 12.25 LBS. PER FT.
F.W. Dean
EXTRA HEAVY CAST IRON SCREW FLANGES EACH DRILLED FOR FOUR ¾" BOLTS ON 7⅞" CIRCLE
6" WRO'T IRON PIPE
DRILL 3" HOLE ON BOTH SIDES
EXTRA HEAVY CAST IRON SCREW FLANGES EACH DRILLED FOR FOUR ¾" BOLTS ON 10⅝" CIRCLE
COLUMNS
DRILL FOR TWELVE ⅞ BOLTS ON 13" CIRCLE
DRILL FOR FOUR ¾" BOLTS ON 7⅞" CIRCLE
DRILL FOR FOUR ¾" BOLTS ON 10⅝" CIRCLE
TWO OF THIS WITH BOSS X
TWO OF THIS WITHOUT BOSS X
ONE OF THESE TO HAVE BOSS Y
ELBOWS

FIG. 133.

this important part of the plant is duplicated, and the smaller set is right for the day load, and of course either of the larger sets can duplicate this during the day time.

The steam pressure can be varied to suit the requirements of load, the boilers being designed to carry 140 pounds of steam.

The exhaust steam can be passed directly into the heating system, or through the feed water heater and then to the heating system, or through the heater and then to the atmosphere, or directly to the atmosphere. The fact that such plants as this must operate constantly throughout the year renders a good deal of duplication necessary. In the winter, the exhaust can all be used up without using the heater, and then the feed is heated by the economizer only. Of course a large proportion of the feed in winter consists of returns and is therefore hot.

An oil separator is inserted in the main exhaust pipe before it reaches the heater, and after it leaves the heater a steam separator is inserted to keep back as much of the moisture formed in the heater as possible. This is done in order to remove all conceivable causes of water-hammer.

The exhaust connection to the atmosphere is automatically controlled by a back-pressure valve provided with a dash-pot.

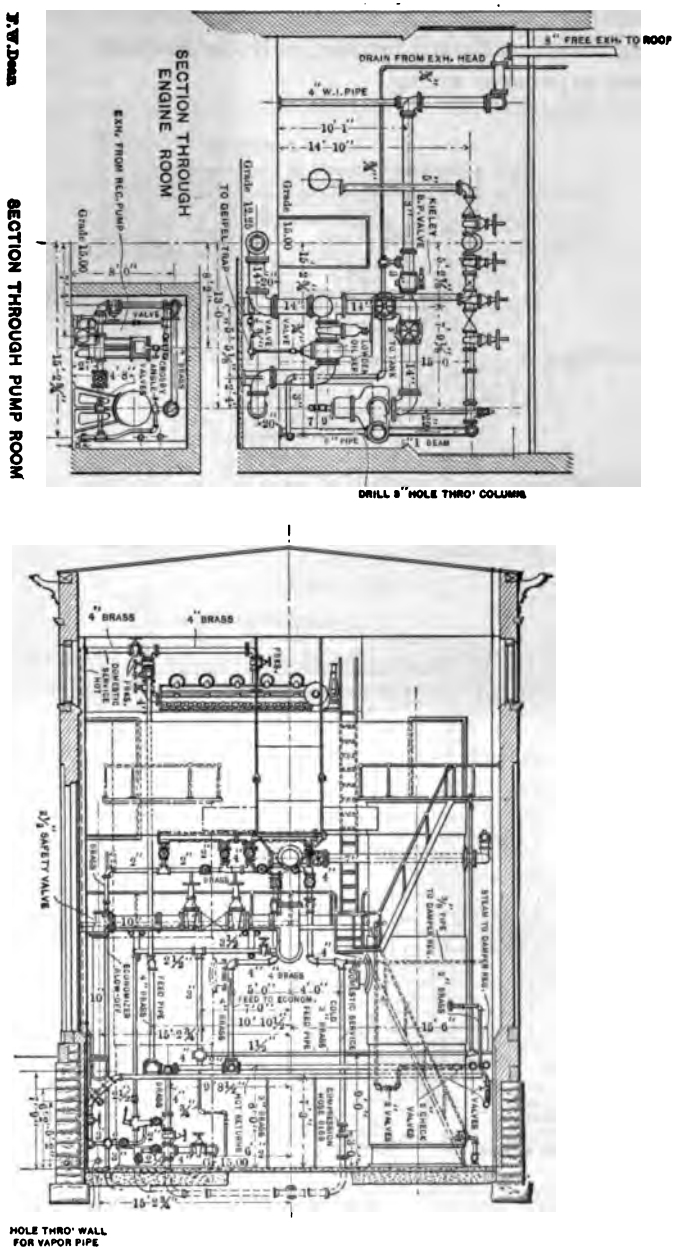
The electrical power is used for lighting, for operating elevators, a refrigerating machine, and various motors, and for apparatus of various kinds.

The voltage is 220 and the wiring is on the two-wire system. There was considerable discussion preliminary to settling upon this, but to the writer no important objection could be made to the system, inasmuch as the exhaust steam is utilized during most of the year, and therefore the extra steam consumption caused by the lower efficiency of the lamps compared with 110-volt lamps is not a cause of extravagant coal consumption. There were other important considerations also that led to the adoption of 220 volts. They were :

(1) The use of half as many generators as would be required by the 3-wire 110-volt system, with lower cost of installation and less cost of maintenance, etc.

(2) A smaller engine room, and therefore a less expensive building.

(3) A smaller building, which, considering the available space, was a very important feature.



CROSS SECTION OF BOILER ROOM

F.W.Dean

FIG. 134.

(4) Cheaper engines and cheaper foundations on account of extending for an outboard bearing only on one side.

(5) Less expensive wiring.

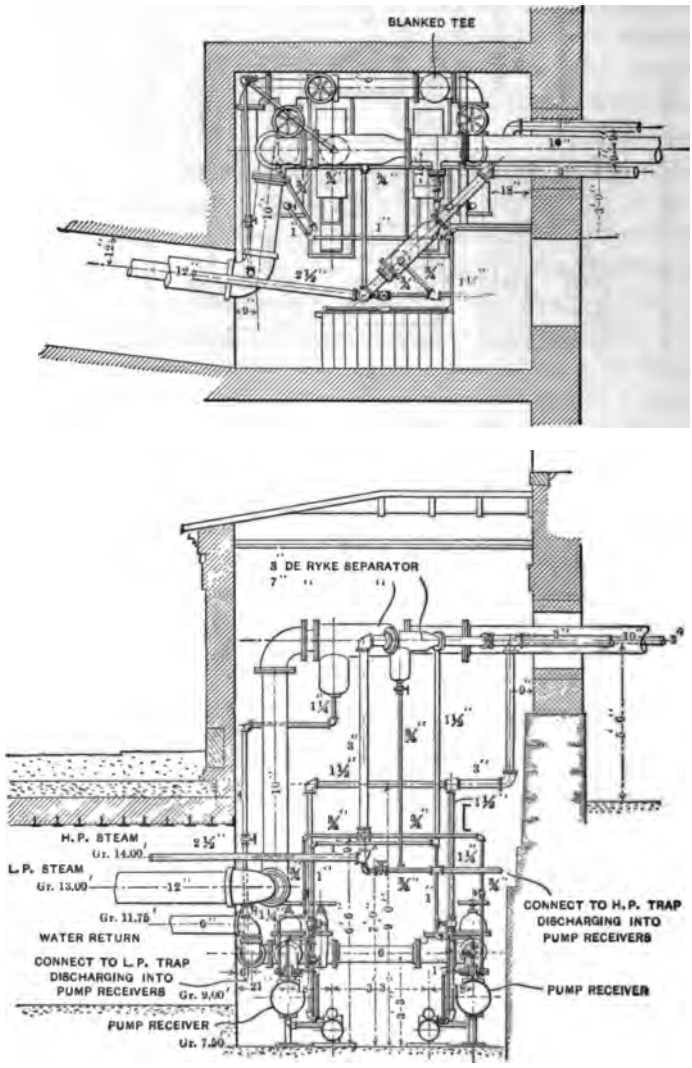
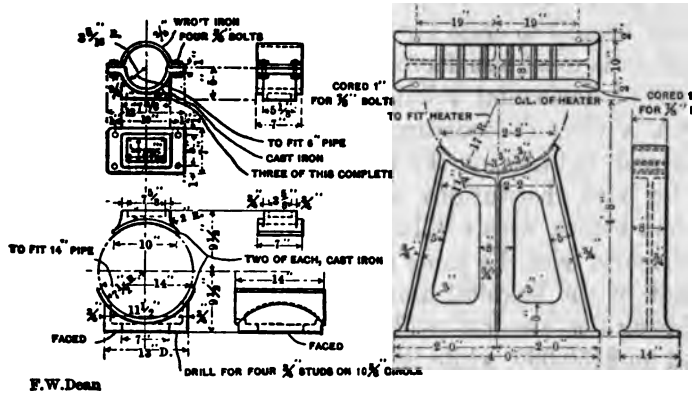


FIG. 135.

As far as the service is concerned the 220-volt system is perfectly successful, and no regret of the choice has ever been expressed.

The size and success of the installation can be quoted as an important precedent, there being about 2,000 incandescent lamps connected.

The amount of fuel to be charged to the separate institutions

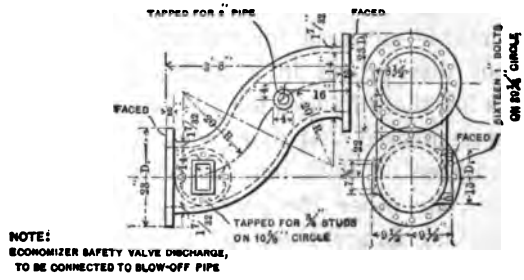


COLUMN CAPS CRADLE FOR HEATER

FIG. 136.

for the use of steam is determined by metering the separate returns. Similarly the charges for electricity are determined by the records of recording watt meters.

The main steam-pipe in the boiler and engine rooms is made



EXHAUST PIPE

FIG. 137.

from detailed drawings by the firm of which I am a member, and the cast portions are made of a mixture of charcoal, iron and steel scrap, which tested for ultimate tensile strength from 35,000 to 39,000 pounds per square inch. For the smaller high-pressure pipes steel castings are in general used for fittings. The pecul-

iar features of the specially designed piping are thick flanges, large and good bolts and plenty of them. By this means all yielding of pipes is forced to take place between the joints, and the joints thereby remain tight. In this plant there have been no leaky joints except where commercial joints were used.

It may be well to state here that the economical result of this installation is most satisfactory. The old plant for the hospital consisted of horizontal tubular boilers with Hawley down-draft furnaces, a Green's economizer, artificial draft, Westinghouse engines and lighting on the 110-volt 3-wire system. The new plant for both institutions, with many more lights in the hospital than before, with 576 lamps, elevator, and other service in the infirmary, uses the same amount of coal as was used by the old plant of the hospital alone. It thereby saves the hospital, considering the amount paid for service by the infirmary, the interest on $150,000, while it cost about half of this amount.

DISCUSSION.

Mr. William D. Ennis.—Mr. Dean's paper is virtually a description of a system of steam piping for power and heating. The writer evidently does not approve of "commercial" pipe flanges. There is a great deal of disagreement on this question. The opinion that standard flanges based on the American Society of Mechanical Engineers' and Master Steam Fitters' schedule of 1894 are of suitable strength for 150 pounds steam pressure was quoted without disapproval in a technical journal last month. Manufacturers list these flanges for 100 pounds working pressure. It should be remembered that there were two schedules issued by the joint committee of 1894, one for pressures under 80 pounds per square inch, the other for pressures above 80 pounds. The present commercial flange, listed by the manufacturers for 100 pounds pressure, corresponds to the latter in its dimensions. Both schedules give the same diameter and thickness of flange and hub for a given size, but an increase in size of bolts is made for the higher pressures. I have seen manufacturers' standard ("commercial") flanges and fittings used continuously on 110 pounds pressure; and have also known of instances where they failed on low-pressure heating or exhaust-pipe systems. There are a great many things besides the pressure to be considered in putting up pipe. Mr. Dean, in his specification for piping in and

about the new boiler house of the Massachusetts General Hospital, called for extra heavy flanges, drilled in multiples of four, on low-pressure work—2 to 3 pounds. Such "extra heavy" flanges are about 2½ times as strong as standard flanges, and cost proportionately more. Perhaps one difficulty with "commercial" flanges at the Massachusetts General Hospital has been that Mr. Dean makes his pipe joints by screwing the pipe through the flange, and then refacing the pipe and flange on centres. He also spot-faces the back of the flange for bolt-heads or nuts. These two facings take off from $\frac{1}{16}$ to $\frac{1}{8}$ inch from the standard thickness of the flange, so that (especially on the smaller sizes) it is not surprising that there should be trouble in keeping the bearing faces rigid. As a remedy for this I have lately made a practice of specifying that the flanges shall be of a standard thickness after facing and spot facing.

Mr. Dean mentions the precautions which were taken to prevent water-hammer. During the construction of the work he describes, there was an accident on the 12-inch low-pressure pipe, I believe, at the point where it enters the Eye and Ear Infirmary (Fig. 124). Was this caused by water-hammer? If so, was the presence of water due to failure on the part of the separator or trap in the pump room? What was the nature of the connection at the end of the 12-inch pipe in Fig. 124, where it appears to be broken off at the Infirmary? The subject of steam-pipe design has been discussed in various quarters lately, and it would be an interesting contribution to the literature of the topic to have a record of the smash which occurred on this particular job.

The use of cast-iron specials instead of welded pipe on the main steam-lines about the boilers is something which invites comment. In a few other plants, notably those of the Edison Electric Illuminating Company of New York, a similar construction has been adopted. The Edison Company uses charcoal iron containing 3 per cent. of aluminum. There is no question but that the saving of joints is an advantage. The difference in cost is in favor of castings as against extra heavy wrought-iron pipe; but good gun iron or other special castings ordinarily cost more than standard-weight pipe with cast fittings and flanges. This would limit the economy in cost due to the use of castings to plants where pressures in excess of 150 pounds are carried. For higher pressures than 150 pounds, I regard cast-iron special piping as of doubtful advantage or economy. The weakest part of such castings is in the fillet

where the flange joins the body of the pipe or fitting, and that is just where, in pipe work, the most strength is needed. Making these fillets of unusually long radius is a partial remedy, but this increase widens the bolt circle and flange diameter, and is therefore objectionable.

Mr. Edward A. Darling.—While the plant described in this paper has much to commend it as a good example of isolated power supply, there are a few points which appear open to question pending further exposition by the author of his reasons for taking the ground which he does on these points.

Let us take first the piping:

There would seem to be no necessity for putting in a separator in the 10-inch exhaust main if the line was properly dripped at frequent intervals; as a matter of fact steam at 3 pounds pressure moving through a main of such ample proportions would have such a low velocity that a separator would be working at a decided disadvantage.

The long exhaust main shown is in itself an admirable separator: it only needs to have the water let out of the bottom as fast as it collects into a drip line and trap.

Mr. Dean does not state the size of his boilers or the collective horse-power of the plant, but assuming this to be at least 400 horse-power it would seem that storage for but 100 tons of coal was inadequate for a hospital plant located in a district which is so liable to suffer from coal famine as Boston. We found in operating a plant of similar character in New York that with more than double the relative coal-storage the danger point was approached not infrequently. While many large hotels and office buildings have practically no coal-storage whatever, and are dependent on a daily supply of fuel, a hospital differs from a hotel in that its guests cannot move out at will. They are at the mercy of the coal pile, and it should be sufficiently large to insure their safety in case of a coal famine in winter weather. I know of one hospital plant that was installed as much as twenty-five years ago where this point was so well considered that coal-storage was provided for the entire winter season.

The use of a spare boiler as a feed tank, while novel and perhaps ingenious in conception, is hardly compatible with good practice, which demands that boilers out of commission shall be drained and have their hand-hole plates removed.

When city mains are closed for any reason it is customary to give sufficient notice to those concerned, to allow them time to provide for a temporary stoppage. A tank large enough to feed the boilers for a couple of hours at least might be placed on the roof, if no other place could be found for it. One of these vertical boilers would surely not contain enough water to feed the other three for 30 minutes.

The attempt to combine a fire-box and a combustion chamber in the boilers described strikes me as a remarkable proceeding, and if no other reason can be given for this step than that the floor space was limited I would suggest that the building should have been designed to fit the boilers and not the boilers to fit the building; and this leads me to say that while the general arrangement of boilers, piping and machinery follows the line of good modern practice, it has as a whole a cramped appearance, due no doubt to the common error on the part of engineers of accepting the architect's fiat as to the amount of space that is available for the vital organism of the buildings which are to be supplied with heat, light and power.

These are matters of the first importance in modern building design, and should be kept to the fore from the very inception of a building scheme.

My own experience, as well as that of other members of this Society with whom I have discussed this point, has impressed on my mind the necessity of combating the views of architects and owners, who are more than liable to relegate boilers, etc., to the cellars, vaults, and left-over parts of a building; anything, in fact, to get them out of sight and out of mind.

The reasons which Mr. Dean advances for his adoption of a 220-volt two-wire system, as against the three-wire system, may, perhaps, have been sufficient to settle the question from the various standpoints which he names; but these standpoints seem untenable when taken collectively.

What objection could there have been to the use of a 110 or 120-volt two-wire system?

The only serious difference in cost would have been in the copper, and that would be met by the difference in efficiency of lamps during at least six months of the year when no heating is done and the exhaust is wasted.

The difference in size of engines would have been measured in

inches, which could not have squeezed the building much, and the cost of a yard or two of extra concrete for foundations would not have proved burdensome.

The figures given to show the saving effected by the new plant over the old are somewhat vague, and while the conclusions are no doubt as stated, it is impossible without further details to see how they are deduced.

Mr. Edwin B. Katte.—In a power plant recently designed for the use of the New York Central and Hudson River Railroad Company, at Albany, N. Y., the 220-volt direct-current two-wire system was adopted, for reasons similar to those stated in Mr. Dean's paper. This plant will consist of 500-brake horse-power, in two batteries of two water-tube boilers each, and four 75-kilowatts direct-connected generators. Current will be used for 2,400 incandescent lamps, 20 arc lamps and operating elevators, ventilating fans and drawbridge motors. A storage battery will be used as a balance to take the large inrush current when the large drawbridge and other motors are started, thus tending to prevent the "flicker" which would be apparent in the lights, especially in the lamps used during the day, when the power load would be in excess of the lighting load. In this plant the exhaust steam is used for heating water, which, in turn, is circulated throughout the several buildings for heating purposes; a live-steam auxiliary heater being used to make up any deficiency in exhaust during the day or in very severe weather; the system being practically the same as that described by Mr. Yaryan in his paper read before the Society last spring, in Cincinnati.

An important, if not the particular, reason for adopting in this case the 220-volt two-wire system was a consideration of the load diagrams, from which it was apparent that power units in multiples of 75 kilowatts would give the most economical distribution of loads during each hour of the twenty-four, both in summer and winter; it was further considered desirable to install machines of the same size, and thus render the plant more nearly interchangeable. Hence, had the 110-volt three-wire system been adopted, it would have required the installation of a large number of quite small machines of less efficiency, requiring more floor-space and more attendance, which, it was believed, would fully offset the lower efficiency of the 220-volt lamps.

The West Shore Railroad has now in operation at its terminal in Weehawken, N. J., the 220-volt two-wire system, used for 500

incandescent lamps, 32 arc lamps, and for motors operating barrel elevators, transfer bridge, and coaling station. This plant has been in operation a little over one year, and is giving very satisfactory service.

Designs are being prepared for light and power plants in the Sixtieth Street freight yard, New York City, and also for the terminal yard and station at Buffalo, N. Y., and in both cases the 220-volt direct-current two-wire system will probably be installed.

Mr. Frederick V. Henshaw.—The reasons given for the adoption of the 220-volt lamp seem to call for some further comment. There is plenty of authority and practice for the use of the high-voltage lamp. The city of London has been putting in 200-volt supply for several years; and within the last few years a large central station plant in the city of St. Louis, and another one in Providence, R. I., have changed their whole system, using 230-volt lamps, with approximately 470 volts on the outside wires of the three-wire system. With respect to Mr. Dean's statement that the use of half as many generators was one of the reasons for adopting the 220-volt two-wire system, I would state, as a matter of fact, that it is not at all necessary to use two generators for the three-wire system—that is, the original three-wire system of Dr. Hopkinson—but that it can also be accomplished with a single generator, without any addition at all to the main dynamo plant, involving increased expense in engines or increased floor space.

It might consume, possibly, a few per cent. more energy than the two-dynamo method. The method most commonly in use employs a small motor-dynamo, which is connected in between the middle wire and the two outside wires. It may be two separate machines, say each of 110 volts, connected in series, or it may be a single machine, with a double-wound armature. And this little machine need not be more at most than 10 per cent. of the total capacity of the plant, costing at most about 20 per cent. of the cost of the dynamo. It can be placed at the centre of distribution, not necessarily in the engine room at all, so that the middle wire does not have to be carried back to the dynamo room. There is also another method by which the same thing is accomplished, in which the main generator has an extra contact ring connected to intermediate points in the armature, and this ring is connected with the neutral wire and takes care of unbalanced load. Another method would be by the use of storage batteries, but that does not apply to the present case.

In regard to the economy of 220-volt lamps as compared with 110, these voltages being approximate, of course, the best present commercial lamp of 110 volts has an economy of about 3-1.10 watts per candle, and the 220-volt lamps about 3-8.10. This means that for an equal number of lights of the same illumination you would save about 18½ per cent. in power by using the 110-volt lamp. Assuming a total of 1,000 lights, and assuming an average illumination of four hours a day for 365 days, and taking cost of power at 4 cents per kilowatt hour, which is probably seldom exceeded, we have an annual saving of about $654, which would be the interest on something like $10,000. This indicates that in such a plant about $10,000 must be saved on the original cost to make it pay to use the 220-volt lamp rather than the 110-volt lamp.

That, I think, represents about the most recent development of the higher-voltage incandescent lamps.

Mr. George I. Rockwood.—I should like to ask Mr. Dean a few questions: First, in reference to the last paragraph in the paper where it says: "It may be well to state here that the economical result of this installation is most satisfactory. The old plant for the hospital consisted of horizontal tubular boilers with Hawley down-draft furnaces, a Green's economizer, artificial draft, Westinghouse engines and lighting on the 110-volt 3-wire system. The new plant for both institutions, with many more lights in the hospital than before, with 576 lamps, elevator, and other service in the infirmary, uses the same amount of coal as was used by the old plant of the hospital alone. It thereby saves the hospital, considering the amount paid for service by the infirmary, the interest on $150,000, while it cost about half of this amount." The statement is too terse, it is too vague. I would like to ask Mr. Dean to amplify it and to state why it was that this plant did better than the old plant. There is no obvious reason why it should (laughter). There is no one in the world more competent to design a good plant than Mr. Dean, and I will not criticize it at all. But I do not see why the old plant was not a good one, too. The fact that his furnace was 8 feet deep is an interesting point. I wish he would give us the design of the boiler in this paper and explain about it, as well as tests on the boiler. As this is a typical installation, the paper should be a very valuable one for us to discuss.

I happened to be putting in a plant almost exactly like this one

and at almost exactly the same time, without knowing it. I put in a plant for the Worcester City Hospital about the same size, a little smaller if anything, carrying steam about 600 feet to the heating system, and it is like this plant in every main particular. I had, for instance, to build a tunnel 210 feet long and carry steam at 140 pounds pressure in a 3-inch pipe all around the corridor basements to provide, at the heating system in the various cottages and buildings, the steam which the old piping system would not carry in sufficient quantity. In fact, I built the plant as nearly like Mr. Dean's plant as it was possible to do it and not be in conference with him. So I naturally do not want to say anything against Mr. Dean's plant. I think it is as good a plant as a man could put in (applause). I wish to call attention, however, to a few details in the paper, and my object in speaking at all is to get a little more information. Mr. Dean has the charming quality of being terse; something that none of the rest of us has, and this paper is a little too bare of detail. I hope he will enlarge the paper before he closes it. I wish to call attention first to what I suppose is the cross-section of a tunnel which he used to carry his pipes from the power plant to the hospital, and to contrast with it the cross-section of my tunnel.

His tunnel appears to consist of a pair of side walls, with a roof composed of horizontal T bars, perhaps, or I beams, placed every 2 feet or so all the way up the tunnel, and that sort of a tunnel I have built before and have not had perfect success with it. It has leaked, and there was no inexpensive way of fixing the leak. The tunnel is from 2 to 3 feet to 6 or 8 feet below the surface of the ground. It is $6\frac{1}{2}$ feet wide inside and 7 feet high. It is not only used for a pipe tunnel through which to carry the steam, water, and gas pipes from the power plant to the hospital, but it is also used as a passageway connecting the hospital with the laundry and connecting the nurses' home with the hospital. So that it is a nicely finished tunnel. The nurses do not object to walking through it. It is lined with white tile brick. But the special peculiarity of it consists in the roof. This is a single arch, running the whole length of the tunnel, composed of three rowlocks, and the abutments of the arch are composed of 8-inch channels. They are the washers, really, of the $1\frac{1}{4}$-inch bolts which are spaced every 5 feet and resist the pressure of the arch. I was advised to put in another form of roof, a series of arches all the way up the

tunnel. The tunnel is on the side of a hill and I felt sure that the water would settle in the haunch of each arch, causing leaks. I put tarred paper between the second and third rowlocks and Portland cement over the top. The result was a perfectly water-tight roof. It was more economical, too, to build the tunnel that way. The channels weighed less than the I beams would weigh with the other form, and can sustain a great thrust. The tunnel is now about a year and a half old, and there is not a crack in it anywhere. The floor of the tunnel is crowning, so that if any water leaked in it would run down the edges and not down the centre. The pipes were hung from a pipe hanger, which I copied almost directly from the Columbia College pipe tunnel, as illustrated in the *Transactions* by the engineer of Columbia University. I found it a very good pipe hanger indeed. I simply hung this pipe hanger from the cross-bars every 10 feet, and have never had any trouble with it at all. I wanted to ask Mr. Dean especially how he heated the water for the hospital taps, how the hot-water service of the hospital and the infirmary was managed, whether the economizer furnished this hot water, or whether the feed-water was used, or whether several feed-water heaters, one in each building, did the heating? At the Worcester City Hospital the economizer does it. I formed a loop from the power-house over the entire hospital. There are some 6 or 8 buildings, several hundred feet apart. I formed a loop running from the hospital to these various buildings, 2 inches in diameter, of brass pipe, with various 1-inch pipes separating from the farther end of the loop and running up to the third story of each of the different buildings. A pump in the power station keeps this water circulating, and at the highest point in the circulation I take in the cold water from the street, providing a check valve immediately back of the inlet, so that the cold water would not run in the reverse direction to the hot-water taps. I thought it a good system, but the trouble that immediately arose was that one could hear the pumping everywhere in the hospital. A hospital is just as quiet as a cemetery, and any little insignificant noise which occurs in the power station on a steam or water pipe can be heard immediately, magnified and reverberating in every ward. That is one of the problems which the engineer has to meet in such a plant. Doubtless Mr. Dean had a similar experience in connection with his work. I provided an air-chamber on the top of the pump, of 8-inch pipe, 6 feet high, and filled it from an air-pressure tank near

by under 20 pounds pressure at all times. That stopped the noise entirely.

I do not see any mention made in this paper of the Johnson Electric Service Company's system of temperature control on various radiators, or any other temperature control. Whether that was used or not I do not know. But I can say from my own experience that such a system effects a large saving of steam, and is, besides, a comfort in the running of a hospital. The various indirect radiators have dampers which are controlled by thermostats, by the compressed-air system, and they maintain a constant temperature in a room, within the limits of the power of the heating apparatus. We have no trouble from water-hammer in the steam pipes. Our 8-inch supply pipe is 350 feet long, and goes up 30 or 40 feet high from the point where it starts to where it separates into smaller pipes. Wherever there is a change in the direction, I simply dripped the pipe with a $\frac{3}{4}$-inch drip-pipe, and carried that back to the boiler-room through a trap.

I see no mention made in Mr. Dean's paper of how power for the laundry is obtained. At Worcester it affords us exhaust steam to use in the heating system during the day, ten or twelve horse-power, perhaps. We heat with exhaust steam on the hot-blast system. Every ward has independent supply and exhaust fans.

Mr. James McBride.—I find that upon page 393 the author says: "It was necessary to employ vertical boilers in order to economize floor-space, and those used were designed by the firm of which I am a member, the object of the design being to permit internal examination, and thus to convert guesswork into knowledge as to their condition. In order to render the combustion comparatively smokeless with bituminous coal, the crown sheets of the boilers are placed 8 feet above the grates, and the result is remarkably good, smoke being rarely seen, and never but slightly." I am very much interested in the smoke business, for I have just escaped from the clutches of the police a week or two ago and I am in daily expectation of being yanked up again. I would like to know whether that boiler has a water leg or not.

Mr. Dean.—It has a water leg.

Mr. McBride.—Eight feet deep?

Mr. Dean.—Eight feet six or seven inches.

Mr. McBride.—I would like also to know what means you apply, other than the deep furnace, to abate the smoke nuisance;

whether you blow air into the furnace with steam jet, or how you get rid of the smoke of bituminous coal.

Mr. Dean.—Nothing is done to get rid of the smoke; it never is formed. There is simply this high firebox. The fact is as I have stated. The coal used is Pocahontas. I am nearly convinced that vertical boilers smoke less than horizontal, probably on account of the draught being applied at right angles to the grate and less obstruction to its passage.

Mr. Reginald Pelham Bolton.—I don't know whether I ought to speak on this subject at all, because Mr. Dean may feel as if I were striving to compare New York practice with Boston practice; but I am sorry to say that if his plant were down here in New York, he would buck against the police department, who would not pass his boiler plant. I refer first to his pipe plan, Fig. 132, and I see that he has only one valve on the outlet from each boiler, and that is at the end of the branch pipe. We think ourselves only on the safe side when we have a valve close up against the boiler flange, and another one at the main pipe.

While I am on this subject I want to say that while his plan now is right as regards his connections to the main, he is going to have lots of trouble when he gets his second set of boilers there, because if he makes the connection straight across to the flange which he has left on the header, I am much mistaken if he does not find them pull apart. I will give him that little tip so that he can prepare for the eventuality in the future.

Mr. Rockwood has gone closely into the question of tunnel construction. I want to raise the question whether a tunnel is necessary at all in such a job as this. I have put 1,000 feet of pipe in a college campus, and heated several buildings from a central boiler station, carrying the pipe in a wooden trench. That was five years ago, and it is still working all right. If the pipes are covered properly, a small trench is, I think, better. Of course there may be other reasons for constructing a tunnel, such as Mr. Rockwood has mentioned here, for nurses to walk through. In my practice I don't get that sort of business. (Laughter).

I want to ask another question which Mr. Dean might consider the next time he gets a hospital to fix up, and that is, whether it is necessary to carry exhaust steam at 2 or 3 pounds pressure, merely because you have to run 800 feet. I have got runs not so long as 800 feet, but they are considerable runs and very difficult runs, and I should not like to put in a great exhaust main like this

with a pressure of 2 or 3 pounds. I am somewhat of what is known as a vacuum and low-pressure crank. I am a great believer in circulating steam at atmospheric pressure. That is what steam was made to circulate at, and what it will circulate at with proper apparatus. I have some buildings with the risers as much as 300 feet from the source of supply. That source of supply is the discharge from cylinders of all kinds; they are discharged at no more than atmospheric pressure, and in some cases a little below atmospheric pressure. I do not see why that should not go in all cases. So far as this instance is concerned, I would have reduced these supply mains sufficiently to go a long way toward paying for the necessary apparatus to make the steam circulate at atmospheric pressure, and I would have had the gain on my engines in the reduction of back pressure. That is a very important point where you have, as in this case, a very high initial pressure on single cylinders only. I don't know the reason for adopting this pressure of 140 pounds, but I have never found any advantage in a single-cylinder engine using steam at much more than 100 pounds pressure. And if you have, as suggested in this paper, the possibility of varying your pressure up to 140 pounds, you are going to have lots of trouble with leaky joints. You are supplying steam not only to steam generators, but to a lot of pumps, and when such pumps are supplied with variable pressures from, say, 80 to 140 pounds, there is likely to be trouble in the steam end.

These may seem rather captious criticisms, but a man who has had to deal with difficulties, and has had to suffer many sorrows, is very apt, when he gets on his feet in a meeting, to try to prevent his neighbors and friends from falling into the same errors—in a Christian spirit. (Applause.)

I want to say another thing, which sounds like a very small feature. There was not any necessity to run two feed pipes to each boiler. I like the idea of multiplicity of steam piping on the ground of safety—the more pipes you have the better you are off, on general principles; but to use two feed pipes is going it too thick. If I specify extra heavy piping for feed pipes in New York practice, I am sometimes called down and asked why ordinary pipe won't do the work, and about a thousand examples are brought up against me if I venture to say that heavy pipe is good practice. In this case the returns form the maximum portion of the feed in winter time, and there is no reason why they should not be mixed with the ordinary feed, and the same pump which does the feeding

in the summer time should do the feeding in the winter time, only providing that it receives water from a different direction. My usual practice in a system of this character is to bring all drips back into a closed tank, and then put whatever amount of auxiliary water is needed into that tank, the same pump doing the work at all times. The blow-off pipes are taken to a separate tank which discharges to the sewer, but in this plant a pipe is connected from it to the injector suction, so that the water in any boiler could be pumped into any other. That would not be allowed in New York city. We are also obliged to put a spray into the blow-off before we pass it into the sewer, which is a very excellent provision very commonly disregarded, as you may see by walking down town on any cold day, when you will notice more steam coming out of the sewers than would come out of a leaking steam pipe.

I want to draw especial attention to the rather novel feature to me of placing a steam separator on the line of the waste steam running to the house-heating system. I agree with the previous speaker in saying that the speed of the steam would be so low that you would be unlikely to get much result, especially if you had previously inserted a feed heater in the line, and thereby produced considerable condensation. You actually create condensation to be afterward removed. That is very much like creating a difficulty, and putting in apparatus to correct it afterward. I want to say at once that this practice of passing exhaust steam, which is intended for heating purposes, through a feed heater, to begin with, and then through a separator is all wrong. You first push your steam through the heater where you create a great deal of condensation, and then send your steam, saturated, into your heating system. To my mind, that is all wrong. The argument in this paper that this was done "in order to remove all conceivable causes of water-hammer" is away off, because it will not remove all conceivable causes of water-hammer. Water-hammer in a radiator, for instance, is caused by the condensation in the radiator. It is not caused only by the fact that the water is coming in the steam to the radiator, but it is caused by the total condensation in the radiator. You have to deal with water-hammer at every point where it is liable to occur, and, as a previous speaker said, every change of grade in this particular job should be dripped, and dripped very liberally, and brought back through a return line and not through a trap, and then you will obtain a complete release of moisture in the steam.

I think that the arguments which were here advanced for the use of a 220-volt system have been already very clearly dealt with by a previous speaker. The arguments which are used are not the arguments which would have borne upon the subject so as to induce this decision. The use of half as many generators as would be required in the 3-wire 110-volt system is not a necessary feature. As regards the size of installations of that kind, if Mr. Dean had referred to me I could have told him of installations of as much as 3,000 or 4,000 lamps which were put in on the 2-wire 240-volt system with success in this city. But the reasons were that we had a specially large motor load, and we desired to keep the whole system of one character to avoid complication. That reason does not always come into account, and I have in hand at the present time one of the largest installations in this city, with 15,000 lights and a motor load amounting to 100 kilowatts, which will go in on the 3-wire system from motives of economy. I have to say, moreover, that there are difficulties in connection with the 220 and 240-volt system which should not be lost sight of. It should not go out that it has all advantages over the lower tension. One of the disadvantages is that the lamps are shorter lived than the ordinary 110–120-volt lamps. Another is that they cannot be placed with impunity in all kinds of positions. When we first began to use them we used to put them in a horizontal position, and the carbon, being very weak, rapidly drooped and broke off. The lamps most recently brought out have supports for the filament, but they remain tender lamps, and a very slight jar will break the filament. Another difficulty is that there are so many apparatuses of an exterior character which are sold nowadays, designed for use with 110 and 120-volt pressure, which the tenants of a building will bring in and put on 220-volt circuits and break them, and will then charge the owner of the building with the cost. For instance, ladies go out and buy electrical hair curlers, and they expect they are going to run them by an ordinary lamp circuit, and they generally run them day and night, never turn them off, and they call on the engineer to find out what is the matter with the electricity. I have seen ten lamps on a portable candelabra connected to a one-light outlet, and when that is hooked up to a 220-volt circuit, destruction is the only word which describes the result. In a recent instance a real estate agent told me that he found a gentleman driving a lathe in his bedroom from one of the lamp circuits. Nobody knows where these

additions may end. A 220-volt circuit is certainly productive of considerable trouble in these respects, although it may seem rather a singular fact.

I want to say, turning to the question of flanges, that I have gotten back, after a sad experience with the flange system, to working out all piping for the old screw connection—I have got down to the belief now that if a pipe system is properly proportioned, properly arranged, and has sufficient spring connections in it, that there is nothing better than the old screw joint, and I will even include the cast-iron fitting in that statement. Flanged joints, you will find, all tend to become heavier and heavier as time goes on. Every man's experience with these joints is one of leaks. He goes to work and makes the flange joints heavier, and draws them together with so much power that he thinks he cannot have a leak, and then the strains in that piping are unknown.

Mr. Rockwood.—What about the Van Steyn joint?

Mr. Bolton.—It is a very good joint, so far as it goes. But these joints all cost money. In this case the joint which failed by breakage was the only point at which relief could be found, so that was the cause of failure there, and not because it was a screwed joint. If your pipe is properly laid out you will be free from undue pressure at any one such point.

The last statement in the paper, to which Mr. Dean has been asked to contribute more details, contains a feature which, I think, may have been the cause to a great extent of the lack of economy of the old system. I see that it had artificial draught. When you put artificial draught in the hands of the ordinary hospital engineer he is very apt to use it as he feels inclined. I have had a case in my experience during the last four years of a hotel uptown where the operating engineer was not satisfied unless he had artificial draught. He had some blowers put in, and when he felt good he would run the fans at one speed, and when he felt bad he would run them at another until he finally came to the conclusion that the chimney was all wrong. So he had a new steel stack built in the back yard. At last the owner began to discover that something was wrong, and he finally thought it might be the engineer. So he sent away the engineer, and now the plant is running very nicely without the blowers.

Mr. Rockwood.—Mr. Bolton has touched on several very important points, but his advocacy of screwed-flange joints surprises me. Mr. Bolton is a little behind the times there, I think. I am

going to take down an elbow next week which has got a screw joint on it which was put on by one of the best of piping contractors. It is leaking through the screw threads. I must take it down and put on another flange, and if that won't cure it, provide another elbow. Engineers oscillate between expense and the screw joint, and they will finally come out on the side of expense every time when they get through experimenting.

Mr. Bolton spoke again of the double-feed pipe system which he says Mr. Dean uses. I do not know whether he has it or not; but Mr. Bolton said that he could not put it in a plant in this city, because the owners would object on account of the cost. We have in Massachusetts a class of men who say: "I have tried to employ a good engineer, and I am going to abide implicitly by what he says. I trust his engineering and also his financial instinct, and if they are wrong, I am going to be wrong with them. If they are right I am going to get the benefit; but I am not going to pay for two men's mistakes." And I want to say that the more owners follow that principle implicitly, the less the money loss will be. This is the result of my experience, and I think Mr. Dean will second it. There is no egoism in that at all, but just common sense. One man will make a certain number of mistakes in any undertaking which he may enter upon, whether he be an owner, an architect or an engineer. That proves to be the case every time. Therefore, it is better to let one man control the work than to have two men or ten men control it. "Too many cooks spoil the broth." How true that is in engineering! One should not choose an engineer in a haphazard, half-hearted way and watch him as a cat watches a mouse; but choose a man whose character is large enough and whose experience is large enough, in your estimation, for him to be trusted with the job and leave him alone. That is what all broad-minded men do to-day in Massachusetts. (Applause.)

Mr. William Kent.—I do not think any greater heresy has ever been propounded on the floor of this room than Mr. Rockwood has just delivered. In quoting the ancient Scotch proverb, "Too many cooks spoil the broth," he has forgotten the scriptural proverb, "In the multitude of counsellors there is wisdom." (Applause) Right down in Boston, near his own home, the biggest job done lately was that job of the Boston terminal. Mr. Kerr read a paper a year ago in which he stated how it was done. The owners called in his firm and advised with them. The firm did not take one man and expect that he would be a big enough

engineer to take the whole plant. They said: "We will appoint a Board of Engineers and we will have them investigate the subject and will then get them into a room and discuss their report." They did concentrate the authority. But they went to a great number of men. The man that trusts one man too much makes a mistake. Some years ago I said that no one man was capable of designing a long line of steam-pipe. It takes two men, because one man will make mistakes and the other man may find them. (Applause.)

Mr. C. J. H. Woodbury.—There is another phase of this subject in that of all the useful applications of the electric light none has been more beneficial to humanity than its use in the illumination of hospitals. The forerunner of this complete plant, which has been described to-night, was a small plant of about 600 lights put into that hospital about twelve years ago, with many misgivings on the part of the trustees of the hospital. The result was so favorable that the City Hospital in Boston soon followed, as did other hospitals, in the use of electric illumination in the wards and rooms. I believe that the one to which I referred was the first instance of electric illumination of a hospital. In the Massachusetts General Hospital the wards did not have any gas pipes in them, and lights were not allowed in there, except candles, in cases of emergency, the lights being in the nurses' pantry, in the passage-way leading to the wards. The Massachusetts General Hospital has been a remarkably progressive institution. It was there that anæsthetics were first used, and many of the brilliant surgical operations of late years were first performed there. After the introduction of electric light they found it was possible to perform a great many operations, particularly those on poor unfortunates who were brought in at night as the worst sufferers from some brawl or assault, and the results of this form of illumination have been exceedingly valuable, because, instead of temporary treatment, operations were performed which had never before been done except during daylight.

The Chairman.—Mr. Dean, would you like to reply to the remarks which have been made?

Mr. Dean.—In one of the first discussions of the paper some reference was made to the large size of the pipe conducting the steam to a distant point, and the result of the slow velocity and consequent inefficient action of the separators which were intended to take the water out, and thereby render the safety of the pipes in the infirmary greater. If, however, the writer of the discus-

sion will examine the diagram on page 403, he will see that in the case of the heating system the separator was reduced from 10 inches to 7 inches on purpose to accelerate the velocity, and thereby throw out the water more effectually than it would otherwise have done. The exhaust pipe was drained in two or three places between the engines and Infirmary.

Some reference has also been made to a smash-up that occurred. Looking at the diagram at the top of page 403, and the same thing is shown in another diagram, there is a 10-inch pipe that comes out in the tunnel. It is more apparent, I think, on the diagram at the top of the page. You will see that the 12-inch pipe joins the elbow. That was very carefully drained, and this break that occurred happened in spite of the precautions that were taken just to prevent that sort of thing. After this a drain was connected to the Infirmary end of the 12-inch pipe in the tunnel, and there has been no repetition of the accident, and it has been rather mysterious, at least, to me. In connection with that I will say that a very interesting thing occurred. That 12-inch pipe had screw-joints screwed as far as commercial pipes usually do, I should say about two-thirds of the distance through. The flange cracked, the pipe pulled out, and there was no evidence whatever of the thread being scraped, upset, or injured to the slightest extent. The flange, after pulling off the pipe, closed together so tightly that you had to look pretty sharply to see the crack.

In regard to the narrow building, somebody said it was best for the engineer to have what he wanted, and make the architect do what the engineer wanted him to do. I fully agree with that in a great many cases. But in this case the width had to be as narrow as it possibly could be, and was determined by me. I had all the width that I wanted, and did not care for more.

In regard to Mr. Bolton's comment about the difficulty to be encountered when the other four boilers are put in on the other side, I anticipate no difficulty. It can be done in a perfectly safe and satisfactory way.

Referring to the criticism that a separator was put in after the steam had passed through the heater, and that the steam ought not to pass through the heater, the fact of the matter is that whenever the whole of the exhaust can be used without passing it through the heater, it is not so passed. Of course then the separator does not have so much to do. But the truth of the matter is that when a man gets up a plan to use up exhaust

steam, he must be sure that he uses it up, and if there is any time in the year that it cannot go to heating, or any use that they put it to in the wards, he had better put it through something to use it up, and if it is more than used up, to make up the supply otherwise.

In regard to the tunnel, I did not design the tunnel just as Mr. Rockwood has. The tunnel is not very far from the Charles River, and I think that all of the ground, possibly not where the tunnel is, but very near to it, has been filled, and high water comes about up to the bottom of the tunnel, and it was very important to have the tunnel as high as possible. It was made rather shallower than Mr. Rockwood's, and in order to have as shallow a roof as possible no arch form was used. Heavy T-irons were put across, and then bricks were introduced and tar liberally used on the courses of brick, and there never has been a leak to my knowledge.

Some remarks have been made which evidently presuppose that we designed the whole heating system of both institutions. We did not do that. We simply connected to what had been done years before. In the case of the Infirmary, the heating had been done from the architect's specification, and the decision to combine the general power plant of the two institutions was not reached until the Infirmary was finished, and we merely conducted steam to one corner of the Infirmary, and it did not lie in our power to use the vacuum system.

In regard to 220 volts, one speaker mentions the use of the three-wire system from one generator. This was not brought to my attention by our electrical consulting engineers at the time.

There is evidently an understanding on the part of Mr. Bolton that the feed water, in case of one boiler being used as a tank, is pumped out of the blow-off tank. That is not the case. There is a valve in the blow-off pipe between the boilers and the tank which can be closed, and then another branch from the blow-off pipe with a valve goes to the injector. In regard to letting the boiler stand full of water, that is not done. In Boston, and no doubt everywhere else, the city gives quite a long notice of the shutting off of the water. I remember a case the other day in which they gave seven hours' notice. In another plant in Boston which had this same provision they immediately filled an empty boiler to the top and it held water for a run of seven hours. When the water was actually shut off they proceeded to

pump the water out of the boiler. By that time the main was repaired.

In regard to the use of the two stop-valves for each boiler I never have put in but one, although I have had my attention called to the possible advisability of it. I presume that any plant some time or other will get into such a condition that you will wish that you had done something else. I suppose that the worst possible thing that could happen in this case would be the corrosion of one of the pipes, and then you might wish that you had a valve somewhere else. I think that it is best to let the future take care of that. I do not believe that there will be any trouble.

I had no idea that this paper would create discussion, but the discussion has become extensive. It shows that there are many members who are sufficiently interested in such matters to go to considerable trouble to examine and write discussions of a steam plant. It shows also, once more, that doctors disagree, but it is gratifying to find so much approval, nevertheless. I am particularly gratified to find that Mr. Rockwood and I were proceeding simultaneously upon the same lines. As interest has been expressed in the boilers I add detailed drawings of them.

Mr. Rockwood asked how it was determined that the new plant was more efficient than the old one. It was determined simply by comparing the coal consumptions before and after. That is all. I cannot fully explain the economy, because I know so little of the old plant.

Mr. Rockwood.—It did not seem credible ; that is all, Mr. Dean.

No. 883.*

AN AMERICAN CENTRAL VALVE ENGINE.

BY E. T. ADAMS, MILWAUKEE, WIS.
(Member of the Society.)

A HOLLOW piston-rod with a valve therein is the essential feature of all central valve engines. The idea of this combination is very old. It was old in this country when Peter Willans took it up in England and made it, literally and figuratively, the central feature of the Willans engine. However, no matter to whom may be due the barren honor of having originated the idea, the brilliant success of Peter Willans made the "central valve" his own, and to him should be accorded the honor pertaining thereto.

Commercially, Willans's success is represented by sales aggregating 320,000 horse-power, chiefly in units of 100 to 300 horse-power; but from an engineering standpoint the measure of his success and the convincing proof of Peter Willans's genius is that he could take this engine, so complex in detail, with its multiplicity of cylinders and its extremely high rotative speed, and actually make it the standard of excellence in the home of the ponderous, slow-going Cornish engine, and among a people so conservative, so opposed to innovation, as our steady-going brethren in Great Britain.

In America, the Willans engine, in spite of its admittedly high record for economy, has been received somewhat coldly. It is manufactured, under license from the English builders, by the Bullock Manufacturing Co. of Chicago, and those who knew the late M. C. Bullock, member of this Society, can testify that its failure could not be due either to lack of proper enterprise on his part, or to lack of that superfine workmanship which the Willans design makes the *sine qua non* of the practical operation of the Willans engine.

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* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

The engine whose valve gear is here described represents an effort to work up the old central valve idea in a form which shall retain the high economy of the English design, but which shall also meet existing American conditions and conform to safe American practice. This has led to so much that is broadly new, and to combinations so widely different from those adopted by Willans, that the designer feels that the title, "An American Central Valve Engine," is entirely justified.

It seems desirable to divide the description of this engine into two parts:

1. A general statement of the conditions controlling design, with an outline of the essential features of the type of engine which is thereby indicated.

2. A brief description of the valve gear of an American central valve engine.

The conditions to be met are assumed to be the usual conditions existing in small isolated lighting and power installations, as typified, for example, by the power plant of a modern office building, and the accompanying design has been worked out on the theory that the essential features of the engine best adapted to this class of service should be as follows:

Moderate Speed, both relative and absolute; that is, any engine should be capable of being operated with safety at a speed 40 to 50 per cent. in excess of its rated speed; and for the service here specified the absolute or rated speed should not exceed 200 to 300 revolutions per minute, depending on the size of the unit. The latter condition tends to reduce danger of vibration, while the former tends to lower cost for attendance, depreciation, and repairs, and in a way may be regarded as insurance against careless design, bad workmanship, or too high rating.

A Vertical Engine, because it requires less floor space, and avoids the tendency of piston and valve to wear down and cause leakage, which is so frequently a source of trouble in horizontal engines. This also involves the proposition that a vertical piston-valve, of fixed travel, properly fitted with rings, and working on a seat so designed that "shoulders" can not be formed, can be made tight initially, and will remain tight, and is by far the most satisfactory and efficient valve, aside from a poppet or a Corliss valve, now in use.

A Single-Acting Engine.—This, if the engine is to be vertical,

is enforced by the limited head room usually available. It is desirable in the particular design shown, in that it makes all parts of the engine so easily accessible; but it is perhaps chiefly desirable since it makes it possible to prevent any reversal of stress on the pins and bearings, thus insuring an engine that will be noiseless, no matter how severe the service demanded, or how limited the opportunity for adjustment.

A CENTRAL VALVE ENGINE, because it allows ample port opening with very low clearance; because it affords practically perfect drainage of the cylinder at all times, is simple, compact, accessible, and allows the lowest possible number of high-speed moving parts.

A COMPOUND ENGINE, provided that the gain in economy shall justify the expense. Now, the assumed conditions indicate that the engine must be non-condensing, that the load will be variable, that the steam pressure will be low, and that for many months in the year the exhaust can be utilized in the heating system. All these factors are usually urged as indicating the use of a simple engine. It should be noted, however, that the poor showing of non-condensing compound engines under variable load is due very largely to faulty steam distribution. This trouble is not inherent in the type, and can be avoided. At the usual pressures, 80 to 125, now classed as "low," the range in temperature is still very great, and should certainly be divided when possible. How far down the scale of pressures this may profitably be carried is indicated by the gain in economy secured in the so-called "Cornish cycle" by guarding the cylinder from the small drop in temperature corresponding to the difference between the terminal pressure and the back pressure. During the months when the exhaust can be used for heating there will be long periods, in spring and fall, when the supply from a simple engine will exceed the demand, and it is an unfortunate fact that the periods of maximum demand for heat and maximum demand for power are usually at opposite ends of the day. In the design here presented, the cost of a compound engine will be only slightly greater than the cost of a simple engine, and, as compared with the usual design of simple automatic engine, should require from 30 to 50 per cent. less steam, with proportionate decrease in fuel required.

COMBINED THROTTLING AND VARIABLE CUT-OFF.—With variable load, maximum economy will be secured by a combination of

throttling control for light loads, and variable cut-off to allow capacity for heavy overload. This is shown very neatly by the accompanying diagram (Fig. 138) adapted from Willans steam-engine trials. The line ABC gives the variation in total water per hour, with variation in load, when the initial pressure is constant and cut-off is varied. The straight line DB gives the variation in total water per hour, with variation in load, with throttling control and a fixed cut-off corresponding to B. Evidently the throttling system gives the better economy for all loads lighter

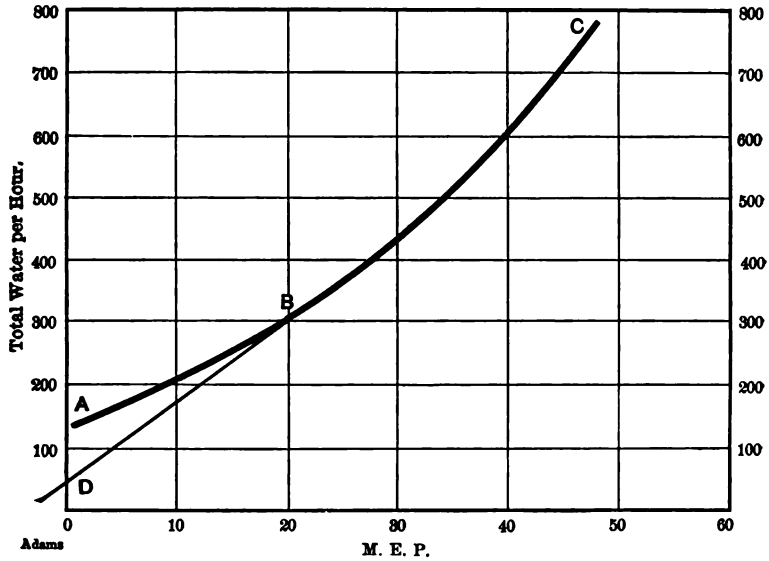

FIG. 138.

than that corresponding to the point of tangency between the straight line and the curve, and manifestly the ideal plan for the conditions here assumed is variable cut-off from C to B; cut-off becoming stationary at the latter point, and all lighter loads to be met by throttling; the variation in total water per hour under the combined throttling and automatic system of control being given by the curve DBC, which corresponds to a very moderate variation in water per indicated horse-power for the extreme range of load.

This description of some of the essential features of this engine and of the reasons for their adoption leads up to the following brief description of the valve gear and system of regulation.

THE VALVE GEAR.—Fig. 139 is a section taken through the low-pressure cylinder at right angles to the shaft. It is intended to illustrate the action of the valve gear and does not show the actual construction of the engine as a whole. As shown in the cut, the low-pressure crank is on its upper centre, and the main valve is open by the lead. The course of the steam at this

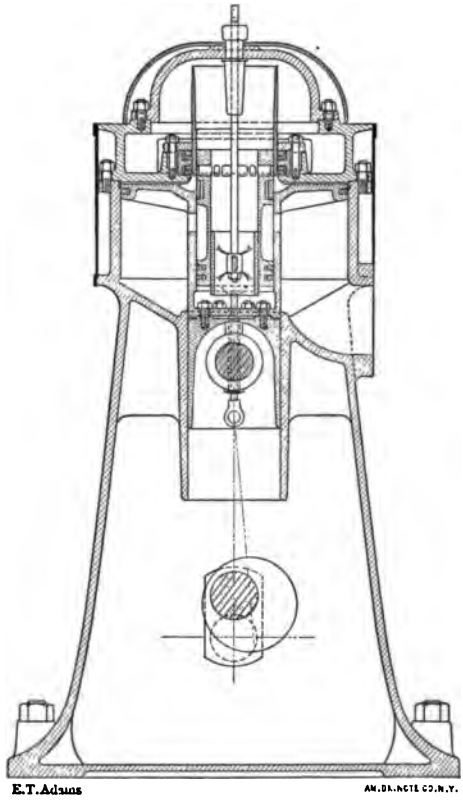

FIG. 139.

instant is from the space above the cylinder head down through the hollow piston-rod and the ports in the main valve to the upper side of the piston. On the return stroke the valve will open a passage between the two sides of the piston, and the exhaust simply passes from the space above the piston to the space below it. On the low-pressure side the latter is in communication with the exhaust; on the high-pressure side it forms part of the receiver. The main valve is a balanced piston-valve,

driven by fixed eccentrics on the crank-pin, hence the valve has a motion relative to the hollow piston-rod, which is proportional to the throw of the eccentric, and both valve and rod have a motion relative to the frame, proportional to the length of the crank. The former motion controls admission, release, and compression; the latter, as will presently be shown, controls cut-off.

The main valve is designed chiefly with reference to the clearance. In the sketch submitted, the stroke is short and clearance is about 3 per cent. The main valve is designed to release very late in the stroke, and to compress to usual receiver pressure, hence the main valve will have a fixed cut-off at $\frac{3}{4}$-stroke or later. This, however, is merely a secondary cut-off, a safeguard against leakage through to the exhaust. Cut-off proper takes place at practically full piston speed, when the ports in the main valve run behind the stationary cut-off sleeve, and variation in cut-off is secured by adjusting the height of this sleeve. Evidently the cut-off sleeve has this in common with the ordinary throttle valve. It is stationary when the load is constant, and only needs adjustment when there is a change in load. Hence the two may be controlled by the same regulator, and if they shall be so combined and adjusted that fixed cut-off shall never be earlier, and the throttling action of the valve shall never extend later than that point of cut-off which affords maximum economy, say $\frac{1}{4}$-stroke, we secure the ideal system of steam distribution for an engine subjected to variable load, with the further practical advantage of a high-speed engine without any high-speed rocker arms and other flying parts in its regulator connections.

As is to be expected in any departure from beaten paths, many interesting problems have arisen in the development of this design, practically all of which have been omitted here, in accordance with the belief that the general engineering propositions laid down at the outset are of more general interest than the details of any particular engine. It is always true that how or by whom any work shall be done is ever of less importance than the result to be attained.

And in brief the result here sought may be called the reconstruction of the simple automatic engine. The time has come when it should be radically changed or should be replaced by something better. In every essential part, save only in regu-

lation, it fails to satisfy the conditions with which it is confronted. Its steam consumption in the cylinder is perhaps moderate enough, but the leakage direct to the exhaust is enormous. Its first cost is perhaps low enough, but its cost at the end of ten years is beyond all reason. In its day it was perhaps good enough, but that day is now past, and the time is ripe for the substitution of a type free from the restrictions imposed by early mistakes, and by the traditions of its past, for a new and better type to meet the new demands of a new century.

DISCUSSION.

Prof. R. H. Thurston.—During my college days—which were also days of most profitable work, in odd hours and holidays, in shops and drawing-rooms of a steam-engine building establishment—I, at one time (1857–59) gave some attention to a central valve engine, embodying the main principles of the Willans, and I presume that some of my rough drafts and sketches are still in existence among my papers of that date. The admirable features of close working of valve to cylinder and the resultant minimum possible port-space seemed to me at that time so important a matter as to justify some sacrifice in other directions to secure it; but I was too busy with immediately imperative work of other sorts to perfect a plan which I was sure might be made practically useful. My judgment has since been confirmed by the success of the Willans engine; which has certainly proved itself a very efficient machine. Apart from the reduced "dead spaces," I was not inclined to claim advantage for that type, and since the practicability of placing valves in the heads, as has been done by Corliss and Reynolds and others afterward, has been proved by experience and has thus accomplished the same end, for some forms of valve gear, at least, in a better way, I have thought less about my old plan. With the piston-valve, however, it has seemed to me the one desirable construction; for, as usually applied, that valve, excellent as it is from its balancing so perfectly, introduces such enormous port-spaces that its advantages, on the whole, may well be questioned where maximum economy is imperative.

For the introduction and perfection of the central valve engine, Willans is certainly entitled to all the honor which Mr. Adams demands for him. But he is entitled also to honor—

possibly in even higher degree—for the scientific work which he performed in connection with that achievement, and, in the eyes of the professional engineer, especially for his beautifully scientific and sound methods of development of its form and proportions and for his methods of revealing its excellencies and defects, of promoting the former and reducing the latter, finally developing, and laying before the profession, the whole physical theory of the machine in a more complete and admirable manner than was ever before seen since Watt began his work by making it a study as a problem in applied science.

Mr. Adams—whose work I have had the pleasure of watching from its inception, when he was at Cornell and in Sibley College—has made a *restudy* of the whole problem by similarly careful and exact methods, and his new plans seem to me worthy of careful consideration.

I think that he restricts himself needlessly, however, in the proposition relative to speed. I see no reason why he should not follow Mr. Porter and design his engine for a practically perfect balance, standing and running, of all its parts, and, where desired by users, place his engine in competition with the professedly high-speed engines of the time. There is no trouble about driving a high-speed engine at moderate speeds where desired; but there may be serious trouble in working a low-speed engine, not particularly designed for perfect balance and high speeds, up to often desirable velocities. The final choice of speed may be safely left to the user, who, in these days, can always have at hand expert advice in matters of detail.

The advantages of the vertical engine have come to be tardily recognized in stationary engineering; but I think that they are undoubted. At sea, where we have the most trouble of all problems in steam-engine design, they have been compulsorily adopted, and have proved entirely satisfactory for many years past. They are only now coming to be accepted on land as a most desirable type; although the builders of pumping engines introduced them years ago, displacing the old and long-standard beam engine—then the only representative of the vertical engine. On large sizes, the engineer-in-charge often objects to the inconvenience of climbing about the engine in his inspections; but, on the whole, there is little doubt, I think, that this is the position in which to set the steam cylinder. The engine

is also cheap to build, compact, occupying little floor-space and, as a rule, none too much head-room; it is long-enduring and economical. The proposed single-acting feature seems to me desirable for high speeds and small engines, but not so for large powers. The piston form of the central valve is ideal in respect to reduction of waste space and when properly fitted in a well-designed cylinder, in giving opportunity to relieve the cylinder of water; which was an advantage perhaps most emphatically urged by Willans, who thought the presence of water in the cylinder not only dangerous, as all engineers admit, but destructive of economy. One of his primary points in design was a construction permitting the immediate sweeping out of all water from the cylinder, with the opening of the exhaust. In fact, this was a point recognized no less clearly by American engineers long before him, as seen in the work of Corliss and Greene and their contemporaries.

Compounding, in the present state of the market and of engineering practice, is the unquestionably advisable plan, and, I think, for even much smaller engines than have been usually built in that form. The smaller the engine the more wasteful, other things equal, and the larger the opportunity for gain by this device, economy of steam being considered; while I imagine it will be found that the finance of the case will often dictate this construction even more imperatively than in large sizes. That is a question easily settled for any given case and time and state of the market, and no builder need remain uncertain as to the best policy in adopting a new design. As a rule, with proper proportions, the compound engine with its boiler will cost less than the simple engine with its boiler, and the "plant" will give a double profit over the simple machine and its accessories. In the comparatively rare case in which the exhaust steam can be used as profitably as if taken direct from the boiler—and its amount thus becomes unimportant where all the exhaust from the most wasteful engine can be used profitably, as in a woolen mill, where it can go to the kier-house or the dyeing department, and there have all the value of prime steam—it is, of course, a matter of no importance how wasteful the engine may be, or what, or how cheap, the type and proportions and construction adopted for power purposes.

Mr. Adams makes a good point in his discussion of the values of throttling and expansion regulation; the one having its place

at very light, the other at practically full loads of a well-constructed engine. He was, I think, one of the first to investigate this matter experimentally in the course of his student work at Sibley College.*

The details of his design are, in my opinion, worthy of careful examination and study. They include some very interesting points.

Mr. Adams, in this bit of engineering design, seems to have sought a combination of efficiency with low costs of construction which should, perhaps, result in the best possible combination of costs and economies; complying with a principle which I have for many years enunciated in some such form as this: That efficiency is most desirable which, on the one hand, cannot be lessened without loss more than commensurate with the gain in other directions, financially, and which cannot be increased without producing a greater accession of cost than can be compensated by the gain in economy of operation. It is what I have been accustomed, for a generation and more, to designate as "The Golden Mean" in economies; the point at which the mechanism in question earns most, *net*, to add to dividends. This machine is to compete, as I understand, with the common, simple single-valve automatic engine; but I see no reason why it should not quite as well, in many cases if not in most, enter the field with the high-speed compounds.

If this valve can be made tight to start with, and *kept* tight, as I am inclined to think it can with good water, free from acid or sediment, I see no reason why it should not give permanent and good economy. The cut-off sleeve is, apparently, the principal point of originality; but the whole machine gives evidence of thoughtful and painstaking work. It is intended, I am told, to be employed as an "automobile" engine and should there find a large field. If manufactured in a few carefully selected sizes, with provision for standardizing and rigid inspection, there should be obtained a good business and a cheap engine—conditions advantageous to both maker and user.

Mr. F. A. Scheffler.—Mr. Adams's very interesting paper is, unfortunately, "shy" on the details as to how the combination in regulation of the fixed cut-off and the throttling action of the

* See "Manual of the Steam Engine," Vol. II., pages 566–68, for a case investigated as above.

valve is effected, but as he has used the phrase "If they shall be so combined, etc.," I take it for granted that some day he expects to accomplish practical results from such a combination, *if* he has not already done so. It is to be regretted, however, that this feature was not clearly shown in this paper.

At the top of page 428 he states that the compound engine of the "American central valve" type, as compared with the *usual* design of simple automatic cut-off engines, should require from 30 to 50 per cent. steam. This means that this compound (non-condensing engine) will use from 15 pounds to 21 pounds steam per horse-power per hour. This is a wonderful result, and will require substantiation by Mr. Adams before he can expect the majority of his readers to believe any such results can be obtained by a central or any other kind of valve engine.

Mr. Robb.—I think Mr. Adams has a number of very nice points on this engine, but I would like to ask him whether he has made any provision for balancing the pressure of the trunk, which forms the crosshead of the engine, and also whether he makes any attempt to use compression to overcome the inertia of the reciprocating parts on the down stroke.

*Mr. Adams.**—I would say, in reply to the last speaker, that, as previously stated, this engine is in process of development, and many points are not finally decided; but, as here shown, the pressure on the trunk is used to help balance the inertia forces due to the weight of the reciprocating parts, as, in an engine of this type, the clearance is too small to be of much assistance in bringing the reciprocating parts to rest at the end of the stroke.

As to the clearance in an engine of this type, any one who has studied it will notice that it is divided into two parts—first, the clearance proper, which goes back as far as the valve, and is in the engine shown about $\frac{1}{2}$ of 1 per cent, while the total clearance, which includes a second part, in which partial expansion takes place during each stroke, is less than 3 per cent. of the low-pressure piston displacement. Now, with a small amount of clearance, that is not enough to bring the reciprocating parts to rest with any degree of comfort, with a high speed especially. I rely therefore very largely upon the area of my piston—which which would have high-pressure steam in the high-pressure

* Author's closure, under the Rules.

side and receiver pressure in the low-pressure side—to bring the reciprocating parts to rest. If there is no reversal, then we have our constant pressure. On the downward stroke there is no provision made.

Regarding Mr. Scheffler's question as to the steam per hour, I take issue with him in saying my statement would mean a water rate of 15 pounds. I should be very well content if, in practice, engineers would give it an everyday rating, with moderately variable load and ordinary operating conditions of 24 to 25 pounds of water. Of course, under best conditions, it should do not far from 25 per cent. better than this. I have tested quite a good many simple and compound automatic engines, and those that have got under 30 pounds have been few and far between. Those that have gone over 40 pounds have been in the great majority.

To those who know the cost, under usual operating conditions, of the power output of practically all existing high-speed automatic engines it will be evident that there is a great field, commercially, for an engine which shall combine the high economy of the Corliss with the low first cost of the automatic. It is along this line that the engine here described is being developed, and, because this line is purely commercial, it seemed desirable to omit from this paper all details, except such as were novel or were considered purely from an engineering standpoint. This will explain the lack of detail to which Mr. F. A. Scheffler refers.

Regarding the question of economy to which Mr. Scheffler refers, it should be noted that while practically all engines are guaranteed at most favorable cut-off and under steady load, yet engines are largely bought on an engineer's estimate of what such engines should do under usual operating conditions, with such variations in load and cut-off as are met in ordinary practice. In the case of the ordinary automatic engine there is practically no relation between these two; for, while it is possible to put such an engine in condition to make a fairly economical showing on a short test, it is well understood that under actual operating conditions the water rate will be probably 50 per cent., and possibly 100 per cent., in excess of that shown by an acceptance test for economy; and the reason is, partly, that such engines are not designed with reference to economy under variable load, but chiefly because economy is entirely sacrificed

in an attempt to secure extremely close regulations—that is, the chief source of loss is leakage direct to the exhaust, which can seldom be prevented in this type of engine, even for a short period of time.

The problem, then, as Dr. Thurston so clearly points out, is to produce the engine which shall "result in the best possible combination of costs and economies," and to attain this result under the usual conditions of operation for engines of this class. This makes efficiency under variable load of far more importance than efficiency at most favorable cut-off, and brings into prominence the fact that it is the water rate which shall be maintained throughout the year, and not the rate which may be shown on a snap test, that is of importance, and which should be carefully considered.

Regarding the question as to speed which is raised by Dr. Thurston, there is, as he points out, no objection from an engineering standpoint to speeds considerably higher than those indicated in the paper, but among the other costs of an engine is the cost of selling, and it is the author's experience that this cost is very considerably greater for a high-speed engine than for one to be operated at a more moderate number of revolutions per minute. There is a strong prejudice against high speed, both among engineers and buyers, founded on unfortunate experiences with the single-valve automatic engine, and, while it is possible, and even very desirable, from an engineering standpoint, to drive this central-valve engine at speeds far beyond those possible to the single-valve automatic, yet it has seemed questionable whether it would not be too expensive to attempt to stem the tide of opposition to high speeds which has been raised by the misfortunes attendant on higher speeds for single-valve automatic engines. As an engineering problem, neglecting finance, the speeds should be higher; but, on taking in the financial considerations, the advisability of higher speed is doubtful.

No. 884.*

COMPARATIVE VALUE OF DIFFERENT ARRANGEMENTS OF SUCTION AIR CHAMBERS ON PUMPS.

BY F. MERIAM WHEELER, NEW YORK, N. Y.
(Member of the Society.)

THE members of this Society who were present at the New York meeting of 1892, when Mr. R. Van A. Norris's paper was read, will, no doubt, remember the interesting discussion that followed.† Mr. Norris described certain tests made on the pumping engines of the Nanticoke, Pa., Water Works, showing the economies obtained by receiving a suction supply under pressure, etc. Incidentally, mention was made of the advantage gained by the use of a large air chamber placed upon the suction pipe. In the discussion referred to I called attention to several arrangements of suction air chambers—good and bad—with which I had had experience.

I will repeat, in the latter part of this paper, one of the illustrations I then gave, showing the importance of properly locating a suction air chamber on a pump. I wish to remark, in passing, how few appreciate that it is quite as important to provide an air chamber on the suction connection as it is on the discharge side of a pump. By such practice you will not only prevent water hammer and its attendant evils, but it must be remembered that the moving column of water has considerable dynamic energy, and this should be utilized to improve the efficiency of the pump and not to be a detriment to it.

To avoid the noise and serious effect of water hammer, a suction air chamber should not only be used, but it is most important that it is properly located and of sufficient size. I can cite many cases where suction air chambers have been so placed that they were of little or no use.

Experience shows that water or other liquids, passing under

* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† "Tests of a Pump Receiving Suction Water Under Pressure," R. Van A. Norris, vol. xiv., p. 168, no. 513.

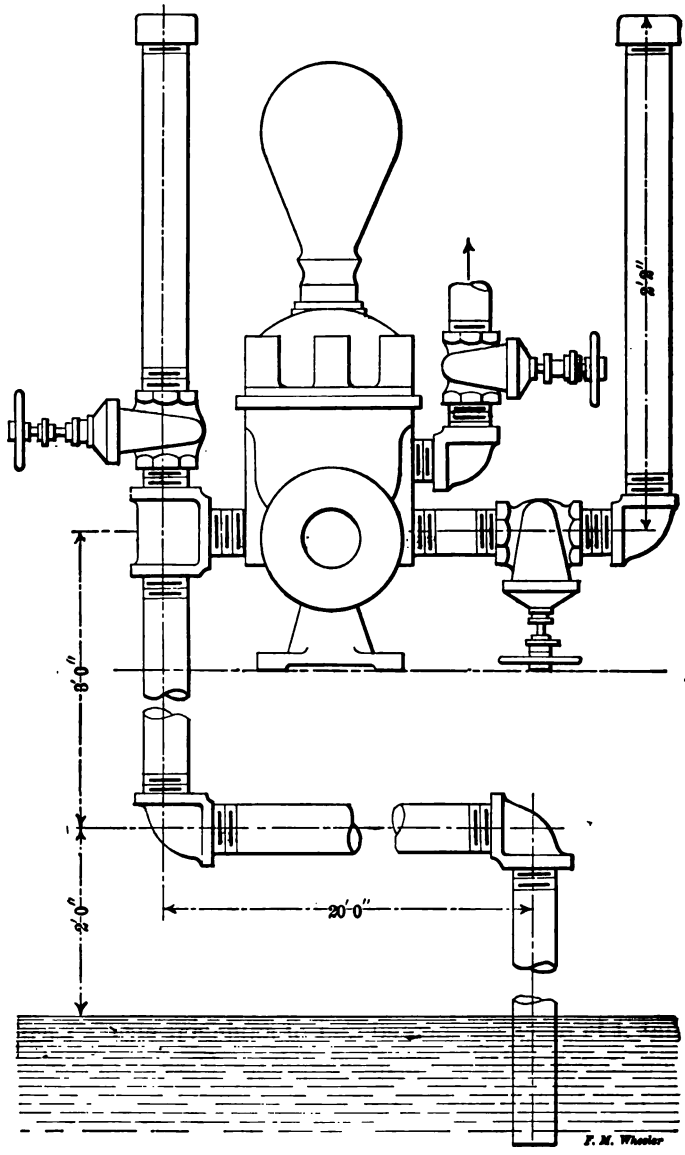

FIG. 140.

or across the opening of an air chamber placed at right angles to the flow, will cause the pump to pound about as much as if no air chamber were used—except at a low rate of speed. Therefore, in arranging suction air chambers I always urge that they be so located that the energy or momentum of the column of water can be expended directly upon the confined air in them. In other words, it is very necessary to get the proper cushion effect for the column of water while the piston of the pump is reversing at each stroke, when running at anything but very slow speed.

I recently tested a small "Blake" simplex compound steam pump, not only to demonstrate the advantage of the suction air chamber, but also to show the respective merits of two arrangements of such suction air chambers. As shown in Fig. No. 140, one arrangement was to have the suction air chamber on the opposite side of the pump to where the supply entered, and placed on an elbow. The other arrangement was the location of the suction air chamber in a direct vertical line with the suction pipe, the air chamber being placed on a tee. Gate valves were provided so that either or both suction air chambers could be shut off and opened at will.

At a slow speed, with both chambers out of use, the pump ran quietly enough, but when the number of strokes was increased to a fair rate of speed water hammer was the result.

To give an idea of the serious effect water hammer has on the piping as well as on the pumps themselves, I would call attention to the fact that this pump (intentionally left unbolted to its foundation, with the piping entirely free to move), at 80 double strokes per minute, produced water hammer sufficient to cause the suction pipe to vibrate at each stroke of the pump, at least ½-inch horizontally. When either suction chamber was opened there was no perceptible movement in the piping, and the pump ran absolutely without jar. The pump drew its supply from a tank below, the total suction lift being about 5 feet, while the length of horizontal suction pipe was about 20 feet.

The indicator cards taken, and submitted herewith, are quite an interesting study. All the cards were taken while the pump was running at about 80 double strokes per minute, with a water pressure of 75 pounds per square inch, the pressure in the steam chest of the high-pressure cylinder being about 60 pounds.

Fig. No. 141 is an indicator diagram taken when the pump was

running with both suction air chambers cut off, while Fig. No. 142 is an indicator card taken at the same time from the suction pipe at a point close to the pump. This latter card graphically demonstrates what "Water hammer" means.

Fig. No. 143 shows an indicator card taken from the water cylinder of the pump with one suction air chamber in use—the one located on the tee connection. Fig. No. 144 represents an indicator card taken at the same time from this suction air chamber.

The gate valve on the first-named chamber was then closed, and the valve on the other suction air chamber, placed on the elbow at the opposite side of the pump, was opened. Fig. No. 145 shows an indicator card taken from the water cylinder with this elbow style of suction chamber; while Fig. No. 146 shows a card taken at the same time from the suction air chamber itself.

It will be seen from these indicator cards that the suction air chamber located on the elbow was more efficient than the other (tee style) suction air chamber. The gate valves were wide open when the cards were taken from the suction air chambers, but it was noticed that when the gate valve on the elbow chamber was opened it required only about one turn to stop the water hammer, while in the case of the chamber placed on the tee, it required nearly two turns of the valve to get the same quiet effect. The suction pipe of the pump was a two-inch size, hence had a cross section area of 3.14 square inches. With the gate valve one turn open it was found, by careful measurement, that the area of the opening was about 0.114 square inch. With the valve two turns open the actual opening was 0.78 square inch. Before completing the test the pump was worked up to the extreme of 120 double strokes per minute, and at this speed it continued to run quietly, there being no vibration of the pump or pipes.*

The illustration I referred to in the discussion of Mr. Norris's paper, and which I desire to here repeat, was the case of the installation of a certain 1,500 horse-power compound stationary engine, where the circulating steam pump, which supplied a surface condenser, had nearly 400 feet of 14-inch suction pipe.

* The identical pump upon which these experiments were made was afterwards shown in operation under similar conditions, in the mechanical laboratories of Columbia University, it having been connected up especially for this occasion.

FIG. 141.

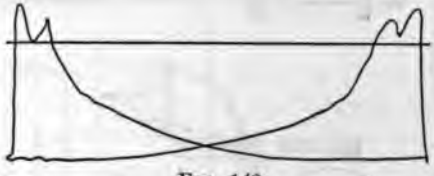

FIG. 142.

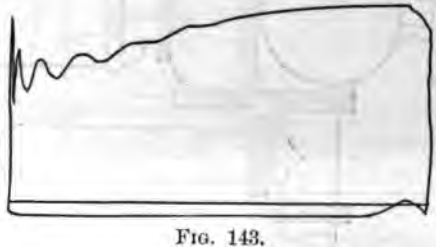

FIG. 143.

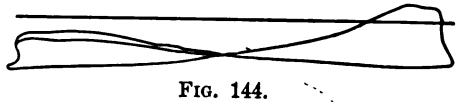

FIG. 144.

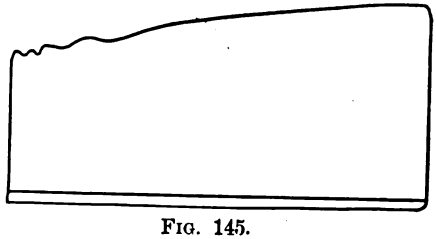

FIG. 145.

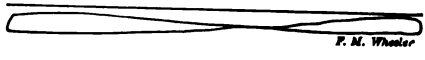

FIG. 146.

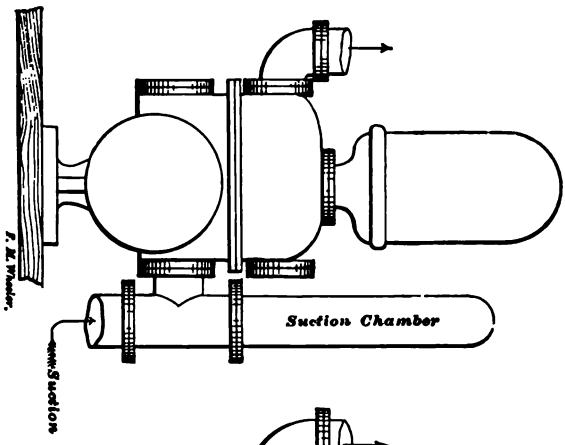

Fig. 147.

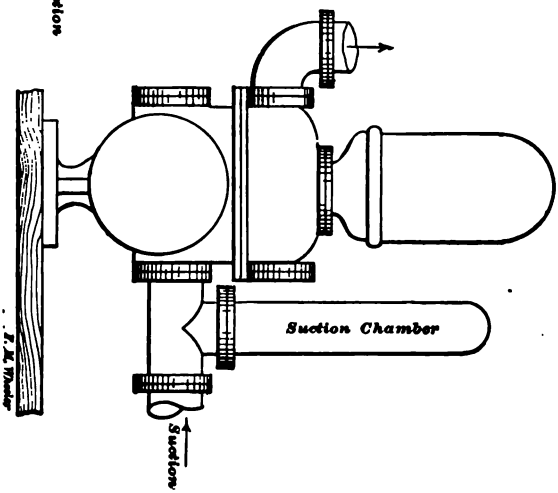

Fig. 148.

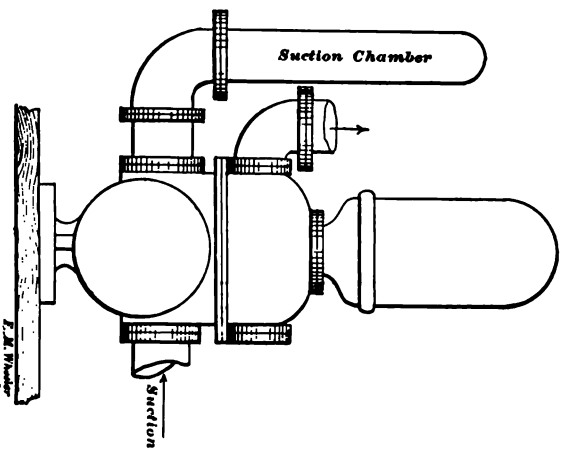

Fig. 149.

I urged the use of a suction air chamber, and understood it would be arranged as shown in Fig. No. 147. When visiting the place later on I was not surprised at the complaint about the noise made by the pump, as I found they had not properly located the suction air chamber, having placed it at right angles to the horizontal suction pipe, as shown in Fig. No. 148, explaining that, for certain reasons, they could not approach the pump with the suction pipe on a vertical line, as was originally intended. The trouble was corrected by removing this suction

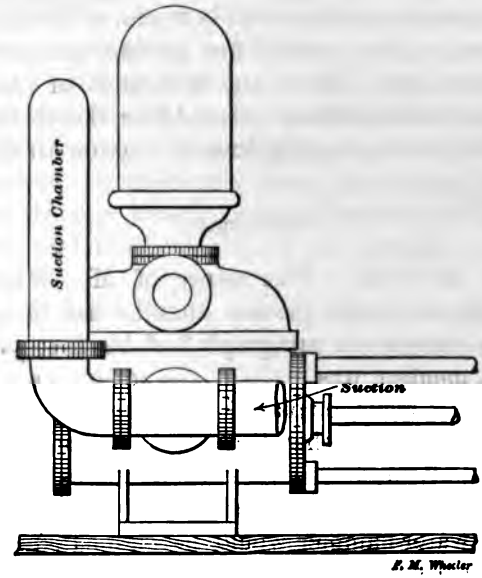

FIG. 150.

chamber from the position in which they had put it, and placing it on the opposite side of the pump with a suitable elbow, as shown in Fig. No. 149. Thus the impact of the water was received over and across the water barrel of the pump into the suction air chamber. It is hardly necessary to say that after this change was made the pump worked with perfect freedom from water hammer.

In marine practice it is often very difficult to properly locate a suction air chamber, owing to limited space. When not convenient to arrange suction air chambers on either plan as shown in Fig. No. 140, as, for instance, when the suction approaches the

pump horizontally, then the arrangement shown by Fig. No. 150 is very satisfactory.

If the manufacturers of pumps would take the trouble to recommend always the use of suction air chambers, and pipe fitters to be made to locate such air chambers properly, then there would be less complaint about jar and noise in pumps, to say nothing about the saving of wear and tear.

This remark applies to pumps of all types, whether single or double-acting, vertical or horizontal; whether receiving water under a pressure or drawing the supply by "suction lift;" and especially to pumps which are liable to run at the higher speeds, as, for instance, in the case of fire pumps, ash-ejector pumps, wrecking pumps, etc. There are thousands of cases of noisy pumps which could be entirely relieved from the ill effects of water hammer by the use of properly located suction air chambers.

DISCUSSION.

Mr. James McBride.—This paper of Mr. Wheeler's is an interesting one, and I am pleased that he has brought it out. Referring to a sentence in paragraph 1 of his first page, he says: "Incidentally, mention was made of the advantage gained by the use of a larger air chamber placed upon the suction pipe." The three words "larger air chamber," to my mind, is the milk in the cocoanut. If engineers and users of pumps could realize the importance of making air chambers of ample capacity, much trouble due to water-hammer would be eliminated. I think the question of capacity is fully as important as the one of position, and in proof of this will cite a case in my own experience. I lately had erected in our works a 7,000,000-gallon duplex pump. This pump was originally put to work without an air vessel on the discharge side, the lift being only about 50 feet. It was thought by the builders that an air vessel would not be needed. Upon putting the pump to service it was found to hammer very badly indeed, so much so as to endanger the safety of the building. An old air vessel, much too small, was brought into use and almost cured the trouble. A larger one, consisting of a piece of 20-inch diameter flange pipe, was substituted, which entirely cured the evil. The pump runs perfectly quiet at all speeds, and all thump and water hammer was entirely stopped.

I wish to take exception to Mr. Wheeler's statement on page 439,

where he says: "Experience shows that water or other liquids passing under or across the opening of a suction air chamber placed at right angles to the flow will cause the pump to pound about as much as if no air chamber were used." I am quite sure that this is not correct, if the chamber is of ample capacity. At least it is not true in the case just mentioned, where a suction air chamber was placed just where Mr. Wheeler says it should *not* be, *i.e.*, at right angles to the flow of liquid. This air chamber is 24 inches in diameter and 12 feet high, the suction pipe is 437 feet long and 24 inches in diameter, and when properly charged with air, gives no trouble whatever. At one time there was attached to the top of this suction air chamber a small pipe leading up-stairs to a condenser having a constant vacuum, for the purpose of assisting the lift with this vacuum—the water reaching the plungers at low tide. At times the air was all drawn from the chamber, which filled with water. Immediately upon this taking place trouble began. When this pipe was disconnected no further trouble ensued. So I am convinced that capacity of air chamber is fully as important as location.

Mr. Kent.—I would like to ask Mr. Wheeler what rule he has for proportioning the size of the suction air chamber.

Mr. Wheeler.—I generally make them in diameter the size of the suction pipe, and in height about on a level with the top of the regular air-chamber of the pump. My experiments show, however, that suction air-chambers even smaller than those used would answer the purpose. In the illustrations the suction air chambers shown are the size of the suction pipe of the pump.

Dr. Thurston.—I would like to ask Mr. Wheeler how he accounts for the fact that the suction air chamber, placed on the elbow, worked better than the one on the tee connection.

Mr. Wheeler.—Those to whom I have spoken in regard to this matter agree with me, in that there is a continuous flow across and over the top of the water barrel of the pump into the suction air chamber on the opposite side. There is certainly less reversal effect of the current than there is in the case of the tee style of air-chamber, and then, no doubt, the passage-way spreading out over the pump barrel, helps considerably. In other words, there is a better distribution of the water in the elbow style of suction air chamber.

Dr. Thurston.—I see another point there which I had not recognized at all before, as Mr. Wheeler shows it—whether the

volume of the air chamber should be a function of the volume of pump, or, rather, of the volume of the suction pipe, or of both, or is there a limit beyond which you will make your suction air-chamber in some proportion to the length of suction pipe, and on the other side of which you will make it a certain proportion of volume displaced by piston?

Mr. Wheeler.—The longer the suction pipe the larger the suction air chamber should be in capacity. As a matter of fact, I find, in the case of a short suction pipe, that quite a small suction air-chamber is sufficient to prevent water hammer.

Dr. Thurston.—Irrespective of volume of pump?

Mr. Wheeler.—Yes, sir. Of course there is always a certain relation of the size of suction pipe to the size of water cylinder, as generally carried out by pump makers. I would increase the height of the suction chamber with increase of length of suction pipe, keeping the diameter of the chamber always the same as the size of the pipe.

Dr. Thurston.—My point comes to me in this way. Ordinarily you set up a steam pump to do certain work with a short length of suction, and, presumably, a certain volume of air chamber on the suction side, which you would put on your pump as it goes into the general market. Now and then you will find a pump working on some long length of suction pipe, as Mr. McBride just gave us the particulars of, and that, undoubtedly, would present a different problem. I was curious to know if Mr. Wheeler's experiments would determine, in the first place, the proper volume of air-chamber for the suction of the ordinary pump put on the market for ordinary conditions, and whether it determines, secondly, another volume for the other case, where the same pump is working on the extreme length of suction pipe.

Mr. Wheeler.—I have never worked that out with any elaboration. What I am trying to do is to get people to use them at all. The ignorance shown in the matter of suction air chambers for pumps is simply appalling. You may say, "Why don't pump makers supply proper suction air chambers with their pumps?" The trouble is, there are hardly two installations alike. Each pump must have an arrangement of piping suitable for the location and work which it is to perform. What I regret to find is that so many begrudge the room and the expense for a few fittings and a piece of pipe, even when you urge upon them the advantages of a suction air chamber. I have for years been trying to get pipe

fitters and pump users to recognize the value of suitably arranged suction air chambers for all types of pumps.

Dr. Thurston.—I think Mr. Wheeler needs assistance in the way of missionary work. If there has ever been one thing that grieved me more than another, it is the fact that in the thirty or thirty-five years that I have been preaching suction air chambers, I never could see that my preaching made the slightest difference.

Mr. Wheeler.—Well, Doctor, I have tried to take it up where you left off, and that is one of the reasons for my bringing this paper before the Society.

Mr. Edward P. Bates.—I would like to inquire if I understood Mr. Wheeler correctly. As I remember, he said something like this: That when he opened the gate valve of the suction air chamber placed on the elbow connection, he found that if he opened it one or two turns it stopped the water hammer, and consequently it proved that this chamber was larger than was necessary. My sense of it is that it only proved that the horizontal connection between the pump and the chamber is larger than is absolutely necessary. It is no objection to have it large. I would like to know if I am right in what I heard.

Mr. Wheeler.—No. I think you misunderstand me. If I remember, I made no remark about the capacities of the suction air chambers. I only said this: that I could secure quiet running by the opening of about one turn of the gate valve of the air chamber referred to, whereas it took nearly two turns of the gate valve on the other air chamber to get the same result. This was to show the comparison of the two arrangements of suction air chambers in getting rid of the water hammer.

Mr. Bates.—Then, as I understand it, you make no special computation between the area of the water cylinder of the pump or the cubic inches in this cylinder and the cubic inches in the suction air chamber.

Mr. Wheeler.—No. Other than what I have mentioned to Dr. Thurston.

Mr. Reginald Pelham Bolton.—Mr. Wheeler's work in this direction has had an unexpected effect on a class of men differing largely from those he has addressed. The plumbing fraternity has adopted the air vessel very widely and successfully in the higher class of buildings now being erected, where the water pressures are largely increased from older practice.

It would be very desirable to obtain some data as to the best

proportions for air vessels, both in suction and pressure lines, for such are not now available.

I disagree with Mr. Wheeler in his view that the pump manufacturers cannot properly supply a suction air chamber. It is they, as much as the user, who want to see them adopted.

It has been, in my experience, difficult to induce the ordinary pipefitters to provide suction air chambers, and even when they are required to provide them, to place them in a reasonably intelligent position.

This has been especially the case in ship work, where the question comes up very prominently in connection with open feed heaters commonly placed on the upper deck level, and providing a heavy suction head to the feed pumps. The hammer, which may be noticed in many such cases at the present time, can be very readily cured by this device of Mr. Wheeler's.

I see that the pump-ends illustrated in this paper are all of one character, and are not the character which is usually met with, at any rate in my practice. The suction chamber is as often entered from the end of the cylinder as from the side, and that has presented a difficulty in raising a suction chamber across the back end of the cylinder. Consequently it appears to me the system shown in Figure 150 is the best and the most readily applied to all purposes.

Mr. Wheeler.—I am very glad of Mr. Bolton's remarks, because they come from one who has had considerable practical experience, especially recently on one of the "Plant" steamships, where the water hammer in the main feed pump was entirely stopped by a properly located suction air chamber. The plumbing fraternity he refers to, however, is not alone in having lots to learn in the matter of suction air chambers.

*I did not reply to Mr. McBride's remarks at the time they were made at the meeting, as I felt there must be something different in the suction pipe arrangement of his pump from what I had experience with in my different tests, particularly in the case I cited of a long suction pipe connected to a pump supplying the surface condenser of a 1,500 indicated horse-power engine. I have since received from him a sketch, showing the exact arrangement of the suction pipe and suction air chamber of his duplex pump, and notice that the suction pipe does not approach the

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*Author's closure, under the Rules.

pump in a direct line. There is a cross-pipe or section of 36-inch pipe between the pump and the suction air chamber to which is attached, on one side, two 18-inch nozzles, each of which supplies one of the water plungers of the pump. On the opposite side of this 36-inch section of pipe, and at the other end, is attached the 24-inch suction pipe, which latter, Mr. McBride said, was about 437 feet long. The suction air chamber, placed within a few feet of this 36-inch cylinder, proved to be of benefit, for there was no doubt more or less "back lash," so to speak, by the current of water being somewhat impeded in having to make two sharp turns before entering the pump. I can offer no other explanation.

Regarding his finding that the connecting of a small air pipe, between the top of the suction air chamber and his condenser, was a disadvantage, I can hardly imagine any different result. What is desired is a reservoir which will act as a cushion to the pulsating effect produced by the pump. A suction air chamber should be only partially filled, and not solid, with water, so as to secure sufficient room for the oscillating movement of the water. In other words, a proper cushion effect.

Apropos of the dimensions of suction air chambers, which came up during the discussion, I beg to submit herewith a letter from Mr. G. A. Ritchie, superintending engineer of the Morgan Line steamers, and recently received by me. This letter bears directly upon the dimensions of the air chamber with which he experimented and is, therefore, of decided practical value.

"A suction air chamber, 4 inches diameter and 30 inches high, was recently attached to the opposite side of the suction of the 10 x 6 x 10 duplex ash-ejector pump on steamer 'El Paso.' A vacuum gauge was connected to the top and a glass water gauge to the side of this chamber, and we then made several tests, as below :

"The first test was made on the ash ejector with 145 pounds water pressure, the pump running full speed with 80 pounds steam pressure, without the slightest jar, the ashes discharging freely overboard without any stoppage whatever. The vacuum gauge indicated 8 inches. The pump was about 4 feet above water line. The pump was then tried pumping overboard, with the same steam and water pressures, working with similar favorable results.

"The suction air chamber was then reduced in height 6 inches by inserting a plug, and the pump was tried on the ash ejector and also on sea discharge, but the pump jarred at the end of each

stroke. The pump was then tried with suction air chamber reduced in height 9 inches, but the pump jarring was more pronounced. The plug was then removed and the suction air chamber left to the original inside height of 30 inches.

"I understand that Mr. Sancton and the chief engineer of the ship are quite elated over the advantages of suction air chambers, and will go ahead putting them on all of our ships.

". . . I congratulate you for the pains you have taken to bring to the attention of people using steam pumps the advantages to be gained by the use of properly arranged suction air chambers."

No. 885.*

TESTS OF THE BOILER OF THE PURDUE LOCOMOTIVE.

BY W. F. M. GOSS, LAFAYETTE, IND.
(Member of the Society.)

I.—The Locomotive and its Boiler.

The boiler tests herein described represent a portion of the results obtained during a period of two years in the course of the regular work of the Purdue locomotive testing laboratory. The principles underlying the action of the testing plant are now generally understood, and need not be elaborately described. It should be said, however, that such a plant provides for the complete operation of a locomotive while permitting it to occupy a fixed position in the laboratory. The locomotive on the plant is fired as upon the road, delivers its power from the periphery of its drivers as it would do if passing along a track, and, while thus operated, is tested with the same facility as a stationary plant. The original locomotive testing plant of Purdue University was described in the "Proceedings of the Society for 1892," vol. xiii. In 1894 this plant suffered damage by fire, and was re-established in a form much more complete than that which it had previously possessed. The new plant went into operation in the latter part of 1894, and is described in a publication issued by the University.†

The locomotive upon which the tests were made is that now known as Schenectady No. 1.‡ It is of the 8-wheel type, and is

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* Presented at the New York meeting (December, 1900) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† A pamphlet to be had on application, entitled "The Purdue University Locomotive Testing Plant."

‡ In May, 1897, this engine was replaced by one of more recent design. It has since been in service on the Michigan Central Railroad, where it is known as No. 422.

shown in outline by Fig. 151. Its characteristics are, briefly described, as follows:

Total weight	85,000 pounds.
Weight on drivers	56,000 "
Total wheel base	22 feet 11 inches.
Driving-wheel base	8 " 6 "
Diameter of pistons	17 inches.
Stroke of pistons	24 "
Diameter of piston-rods	3 "
Diameter of drivers	63 "

The form and principal dimensions of the boiler are shown in Fig. 152. It is of the ordinary crown-bar type, having a narrow firebox and no brick arch. It was designed to carry a pressure of 140 pounds, at which limit its safety valves were usually set. The boiler was at all times perfectly tight, and was kept clean. Its characteristics are as follows:

Diameter waist at front end	52 inches.
" tubes, outside	2 "
" " inside	1.78 "
Number of tubes	200
Length " "	11.5 feet.
Thickness of tubes	.11 inches.
Area of flameway through tubes	3.46 feet.
Width of firebox	34.5 inches.
Length of "	72 "
Height of "	73 "
Heating surface in firebox	132.1 feet.
" " " front head	10.5 "
" " " tubes calculated from outside diameter	1204.3 "
" " " " " " inside "	1071.8 "
Total heating surface, assuming the tube surface to be calculated from outside diameter	1346.9 "
Total heating surface, employed in all calculations, obtained by assuming the tube surface to be calculated from the inside diameter	1214.4 "
Grate area	17.25 "
Ratio of heating surface to grate area:	
Assuming heating surface to be 1346 9 feet	7.81 "
" " " " 1214.4 "	7.04 "
Pounds of water in boiler when filled to middle gauge	8450
Steam space in boiler when filled to middle gauge	52.8 cu. ft.
Ratio of steam space to entire cubical capacity of boiler	.29

II.—The Tests.

The results herewith presented are from the first thirty-five tests which were run immediately following the re-establish-

ment of the testing plant after its damage by fire in February, 1894. The tests were run by senior students in mechanical engineering as a part of the regular routine of the laboratory, and involved observations as to engine performance, as well as those concerning the performance of the boiler. The present paper deals only with the performance of the boiler. While many have aided in the advancement of the work, it is fitting that specific mention be made of the assistance rendered by Prof. Robert S. Miller, junior member of the Society, who, when an assistant in the laboratory, checked all calculated

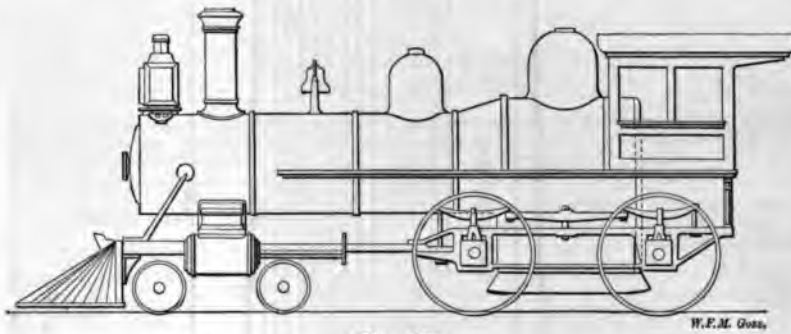

FIG. 151.

THE PURDUE EXPERIMENTAL LOCOMOTIVE, SCHENECTADY NO. 1.

results, and afterwards led in the development of many of the comparisons which are presented.

The final results only are given. These are generally the average of values obtained from observations made at five-minute intervals. In most cases the individual observations were checked by two different observers using separate instruments, or they have been taken by one observer and checked by some form of automatic recording instrument. All derived results have been calculated by two or more independent workers.

A hasty review of the data will disclose some inconsistencies. The number of these could have been greatly reduced, and the general appearance of record improved by the omission of a few tests. From an experimental point of view, however, all are believed to be equally reliable, and there seems to be no more reason for omitting a test, the results of which fall out of line, than for omitting another, the results of which are in line. For this reason the exhibit is a complete presentation, so far as

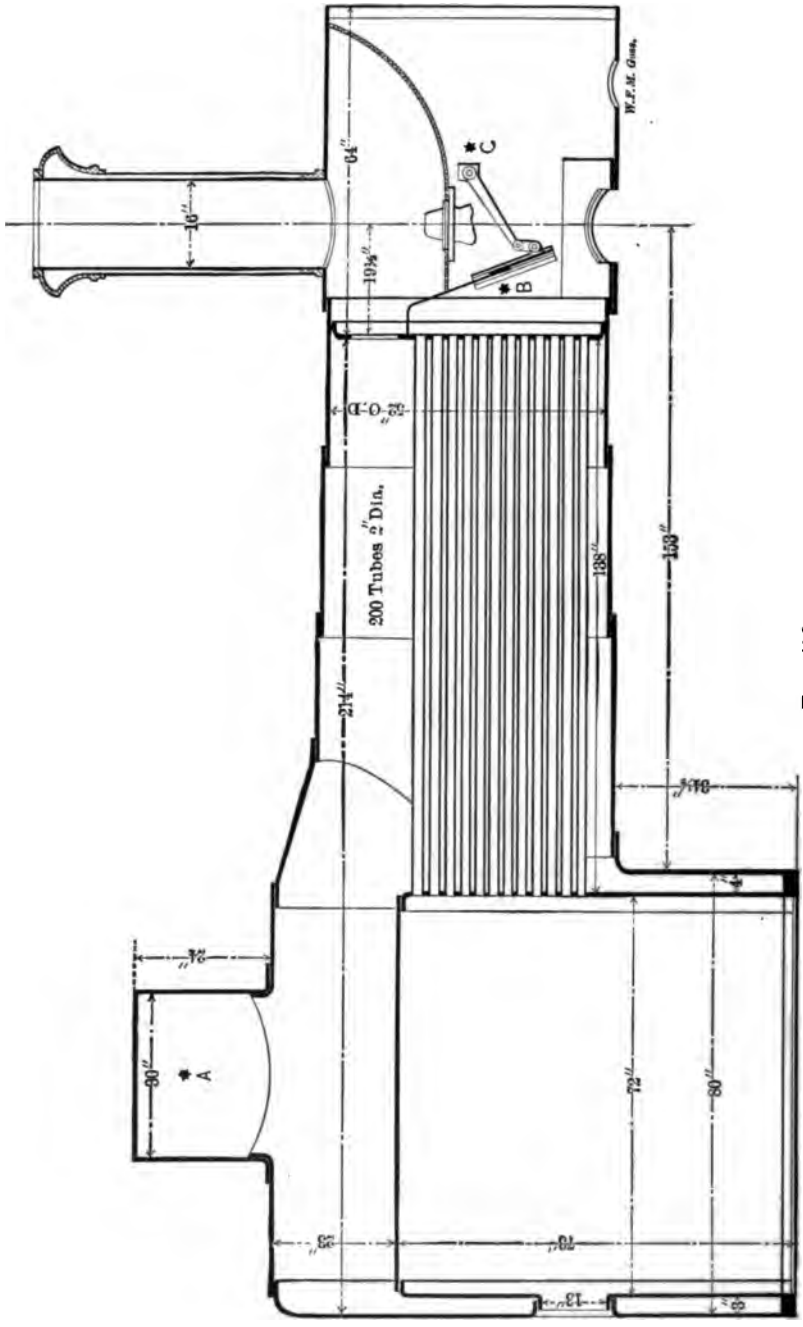

FIG. 152.

THE BOILER OF THE EXPERIMENTAL LOCOMOTIVE.

The calorimeter received its supply from the point A, the temperature of the smoke-box was taken at B, and the draught from the point C.

the boiler is concerned, of all the work undertaken during the whole period covered by the tests.

General Conditions (*Table I.*).—Individual tests may be identified by number, by laboratory designation, or by date. As each of these separate forms of notation express certain relationships, all are given in each table. The tests are arranged in order on the basis of the rate of evaporation, the consecutive number (column 1) indicating at once the relative position of each test, with reference to the factor named. Test 1 is that test for which the rate of evaporation is least, and test 35 that test for which it is greatest.

TABLE I.

GENERAL CONDITIONS.

THE SEVERAL TESTS REPRESENTED IN THIS TABLE ARE ARRANGED IN ORDER OF THE RATE OF EVAPORATION, NO. 1 REPRESENTING THE TEST FOR WHICH THE RATE IS LEAST, AND NO. 35 THAT FOR WHICH IT IS GREATEST.

Identification of Test.			Duration of Test in Minutes.	Average Pressure, Pounds per Square Inch.			Average Temp., Deg., Fahr.	
Consecutive Number.	Laboratory Designation.	Date of Test.		Steam Pressure in Boiler by Gauge.	Atmospheric Pressure.	Absolute Steam Pressure.	Of Laboratory.	Of Feed Water.
1	2	3	4	5	6	7	8	9
1.....	15—1—*A*	Dec. 12, 1894	240	125.9	14.5	140.4	65	53.2
2.....	15—1[b]—*V*	Nov. 23, 1894	190	127.3	14.5	141.8	74	53.8
3.....	15—1—*H*	Dec. 9, 1896	180	123.6	14.3	137.9	73	54.6
4.....	25—1—*A*	Dec. 14, 1894	255	120.1	14.5	134.6	67	53.8
5.....	15—1—*G*	Nov. 9, 1896	180	123.6	14.4	138.0	69	53.3
6.....	15—2—*A*	Nov. 13, 1895	180	129.5	14.4	143.9	79	55.2
7.....	25—1—*V*	Nov. 26, 1894	240	127.1	14.3	141.4	70	52.9
8.....	35—1—*A*	Dec. 17, 1894	180	129.7	14.6	144.3	75	53.2
9.....	35—2—*F*	Jan. 21, 1895	180	155.4	14.7	170.1	71	52.7
10.....	35—1—*V*	Dec. 7, 1894	140	128.9	14.3	143.2	69	51.9
11.....	35—2—*E*	Jan. 16, 1895	180	128.1	14.5	142.6	71	51.9
12.....	45—1—*A*	Nov. 20, 1895	150	128.8	14.3	143.1	76	56.4
13.....	35—2—*B*	Jan. 14, 1895	170	98.4	14.4	112.8	66	50
14.....	55—1—*A*	Nov. 25, 1895	120	124.9	14.2	139.1	76	56
15.....	35—1—*H*	Dec. 18, 1896	160	121.2	14.6	135.8	67	52.6
16.....	35—1—*G*	Nov. 20, 1896	170	125.0	14.6	139.6	74	55
17.....	35—1[b]—*G*	Dec. 2, 1896	170	128.2	14.6	142.8	78	52.5
18.....	25—2—*A*	Oct. 25, 1895	180	129.3	14.4	143.7	85	56
19.....	55—1—*V*	Dec. 18, 1895	120	128.4	14.4	142.8	76	58.1
20.....	35—2[b]—*H*	Feb. 10, 1897	160	122.6	14.5	137.1	74	50.6
21.....	55—1—*H*	Feb. 11, 1897	120	127.5	14.4	141.9	71	52.1
22.....	55—1—*G*	Nov. 23, 1896	120	126.9	14.5	141.4	79	54.2
23.....	15—9—*A*	Nov. 6, 1896	150	122.5	14.3	136.8	79	55.6
24.....	15—9—*H*	Dec. 11, 1896	180	122.7	14.4	137.1	81	53.2
25.....	35—2—*A*	Dec. 19, 1894	180	123.0	14.5	135.7	72	52.5
26.....	35—3—*G*	Dec. 4, 1896	140	125.9	14.3	140.2	70	52.6
27.....	15—9—*G*	Nov. 12, 1896	160	124.1	14.5	138.6	77	53.1
28.....	35—3—*H*	Dec. 14, 1896	120	116.5	14.3	130.8	73	53
29.....	35—2—*G*	Nov. 18, 1896	160	121.0	14.5	135.5	78	53.6
30.....	35—2—*H*	Dec. 16, 1896	120	112.0	14.6	126.6	72	53
31.....	45—2—*A*	Nov. 18, 1895	140	126.7	14.3	141.0	84	55
32.....	25—3—*A*	Nov. 1, 1895	122.5	127.2	14.5	141.7	76	53.3
33.....	35—2—*C*	Jan. 23, 1895	120	143.3	14.4	157.7	71	51.7
34.....	55—2—*A*	Nov. 22, 1895	68	124.0	14.4	138.4	76	58.4
35.....	35—3—*A*	Nov. 15, 1895	120	125.3	14.3	139.6	77	55.5

The laboratory designation (column 2) expresses the speed of the engine, the position of the reverse lever (notches forward of center), and the series to which the test belongs. Thus, 15—1—*A* signifies that the test was made with the engine running at a rate of 15 miles an hour, with the reverse lever in the first notch forward of center, and the test belongs to series *A*. The series letter usually refers to engine conditions. For example, series *A* and *V* represent, respectively, two series run in parallel, with a constant boiler pressure, with the throttle wide open, and at varying speeds and cut-off. For the *V* series the valves were so set that the lead was considerable, while for the *A* series the lead was reduced. As these engine conditions do not in any way affect the boiler performance, the significance of the series letters need not be further defined. The dates upon which the several tests were run (column 3) discloses their actual sequence. The first (No. 2) was run in November, 1894, and the last (No. 21) in February, 1897.

To those accustomed to reviewing data derived from stationary boilers, the duration of the tests (column 4) will appear insufficient. The arguments sustaining the practice involving short tests for locomotives on a testing plant have been presented to the Society's committee having in charge the revision of the code relative to a standard method of conducting boiler tests, and will be found presented in the published correspondence of that committee (Volume XXI., page 112). The tests herein recorded were run several years in advance of the presentation of the committee's final report, and for this reason it will be of interest to call attention to the fact that fifteen out of the thirty-five tests perfectly fulfill the requirements of the present code. In defense of those which are shorter than allowed by the code, it should be said that the writer's opinion on the subject was embodied in a recommendation to the committee to the effect that the limit applying in such cases be the burning of a total for the test of not less than 100 pounds of coal per foot of grate surface. The committee adopted the general form of the recommendation, but fixed the limit at 250 pounds. For two of the tests presented the total fuel per foot of grate per hour is slightly below 150 pounds, and for four others it is below 200.

The boiler pressure (column 5) was practically the same for all tests, save two, and for these it was intentionally higher than the normal in the one case and lower in the other. Pressures

were observed from an ordinary dial gauge at five-minute intervals, and also recorded by a Bristol gauge. To better show the fluctuations in pressure, the chart of this and other recording gauges used about the locomotive have a rapid motion, making

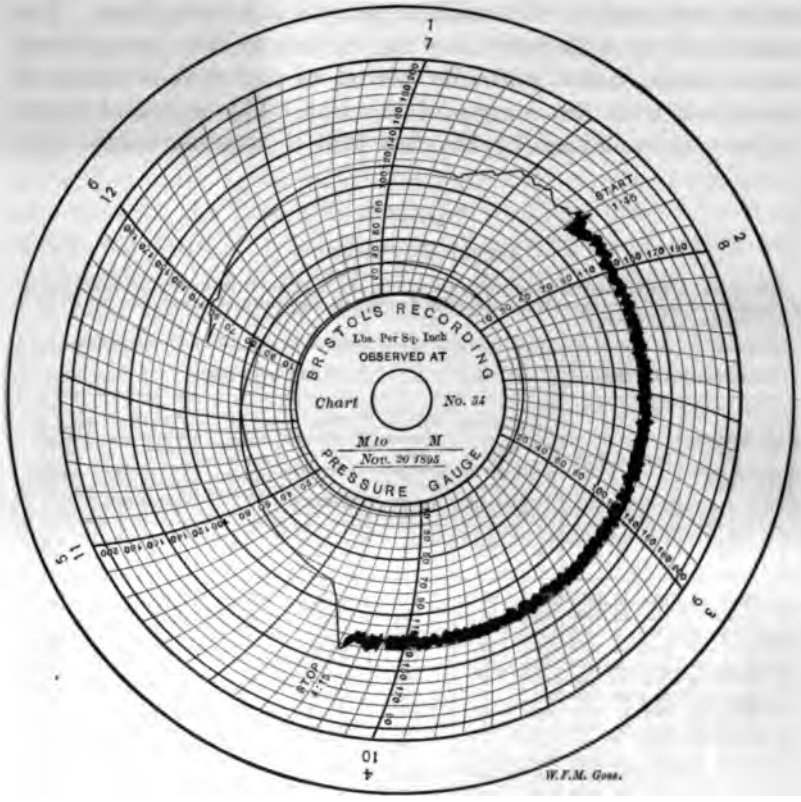

FIG. 153

CHART FROM RECORDING GAUGE, SHOWING BOILER PRESSURE.

a complete revolution in six hours. A sample chart is presented as Fig. 153.

The atmospheric pressure, the absolute steam pressure, the temperature of the laboratory and of the feed-water (columns 6 to 9) require no explanation.

Actual Evaporation (Table II.)—This table shows (columns 10 and 11) the regularity with which water was delivered to the boiler; the total pounds delivered to the injector during the

test (column 12); the pounds caught from injector overflow (column 13); the pounds received by the boiler (column 14); and the rate at which the evaporation proceeded (column 15). In all tests an effort was made to keep the injector constantly in action, but for those of low power the rate of delivery could not be made sufficiently small to permit this being done. The data for a few of the tests show the injector to have been started two or more times, while its period of action is recorded as coincident with the length of the test. This apparent inconsistency is explained by the fact that it was sometimes con-

TABLE II.

ACTUAL EVAPORATION.

THE SEVERAL TESTS REPRESENTED IN THIS TABLE ARE ARRANGED IN ORDER OF THE RATE OF EVAPORATION, NO. 1 REPRESENTING THE TEST FOR WHICH THE RATE IS LEAST, AND NO. 35 THAT FOR WHICH IT IS GREATEST.

Identification of Test.			Duration of Test in Minutes.	Water and Steam.					
Consecutive Numbers.	Laboratory Designation.	Date of Test.		Number of Times Injector was Started.	Minutes One or Both Injectors were in Action.	Total Pounds of Water Delivered to Injectors.	Pounds of Water Lost from Injector Overflow.	Pounds of Water Delivered to Boiler and Presumably Evaporated.	Pounds of Water Evaporated per Hour.
1	2	3	4	10	11	12	13	14	15
1..	15—1—*A*	Dec. 12, 1894	240	22	130	22,415	315	22,100	5,525
2..	15—1b—*V*	Nov. 23, 1894	190	14	129	17,925	135	17,790	5,618
3..	15—1—*H*	Dec. 9, 1896	180	7	126	18,349	126	18,223	6,075
4..	25—1—*A*	Dec. 14, 1894	255	10	236	25,995	100	25,895	6,093
5..	15—1—*G*	Nov. 9, 1896	180	12	127	18,768	72	18,696	6,232
6..	15—2—*A*	Nov. 13, 1895	180	9	149	21,885	44	21,841	7,280
7..	25—1—*V*	Nov. 26, 1894	240	7	213	29,508	32	29,476	7,369
8..	35—1—*A*	Dec. 17, 1894	180	2	180	24,468	100	24,368	8,123
9..	35—2—*F*	Jan. 21, 1895	180	9	149	24,793	460	24,333	8,111
10..	35—1—*V*	Dec. 7, 1894	140	1	136	19,899	0	19,899	8,528
11..	35—2—*E*	Jan. 16, 1895	180	3	175	25,742	45	25,697	8,566
12..	45—1—*A*	Nov. 20, 1895	150	2	146	21,688	15	21,673	8,669
13..	35—2—*B*	Jan. 14, 1895	170	8	158	24,728	173	24,555	8,666
14..	55—1—*A*	Nov. 25, 1895	120	1	120	17,970	87	17,883	8,941
15..	35—1—*H*	Dec. 18, 1896	160	1	160	24,793	70	24,723	9,271
16..	35—1—*G*	Nov. 20, 1896	170	1	170	26,598	35	26,563	9,375
17..	35—1b—*G*	Dec. 2, 1896	170	1	170	26,753	10	26,743	9,439
18..	25—2—*A*	Oct. 25, 1895	180	1	180	28,911	5	28,906	9,635
19..	55—1—*V*	Dec. 18, 1895	120	1	120	19,526	108	19,418	9,709
20..	35—2b—*H*	Feb. 10, 1897	160	1	160	25,834	5	25,829	9,686
21..	55—1—*H*	Feb. 11, 1897	120	1	120	20,514	0	20,514	10,257
22..	55—1—*G*	Nov. 23, 1896	120	1	120	20,791	30	20,761	10,381
23..	15—9—*A*	Nov. 6, 1896	150	1	150	28,582	60	28,522	11,409
24..	15—9—*H*	Dec. 11, 1896	180	1	180	34,403	30	34,373	11,458
25..	35—2—*A*	Dec. 19, 1894	180	1	180	31,354	29	31,325	11,442
26..	35—3—*G*	Dec. 4, 1896	140	1	140	27,060	0	27,060	11,597
27..	15—9—*G*	Nov. 12, 1896	160	1	154	30,877	5	30,872	11,577
28..	35—3—*H*	Dec. 14, 1896	120	1	120	23,446	60	23,386	11,693
29..	35—2—*G*	Nov. 13, 1896	160	1	160	32,886	40	32,846	12,317
30..	35—2—*H*	Dec. 16, 1896	120	3	115	24,793	60	24,733	12,367
31..	45—2—*A*	Nov. 18, 1895	140	1	140	29,313	213	29,100	12,472
32..	25—3—*A*	Nov. 1, 1895	122.5	1	122.5	26,415	14	26,401	12,931
33..	35—2—*C*	Jan. 23, 1895	120	3	120	26,034	25	26,009	13,004
34..	55—2—*A*	Nov. 22, 1895	68	1	68	16,188	277	15,911	14,039
35..	35—3—*A*	Nov. 15, 1895	120	1	120	29,981	109	29,875	14,937

venient to change from one injector to the other during the progress of the tests, and at other times both injectors were in action at the same time. Column 10 merely shows the number of starts made, and includes the record for both injectors. The last column of this table discloses something of the significance of the conditions attending the action of the locomotive boiler. For example, test 35 shows that nearly 15,000 pounds of water were delivered to the boiler and presumably evaporated each hour, or, approximately, 250 pounds per minute. This rate of very nearly a barrel a minute is sufficient to evaporate an amount of water equal to the full water capacity of the boiler in 34 minutes. At this rate, had the injectors ceased in their action, the water level would have fallen between the upper and the middle gauges at the rate of one inch each minute.

Quality of Steam and Equivalent Evaporation (Table III.).—The quality of steam, assuming dry saturated steam to be unity, is shown by column 16, and the percentage of moisture by column 17. Results were obtained by the use of a throttling calorimeter of an approved form, taking steam from a perforated pipe extending horizontally into the dome of the boiler at a point A, Fig. 152, near the throttle opening. Observations were made at five-minute intervals. An examination of the table will show that, in general, the amount of moisture in the steam increases as the rate of evaporation is increased, though variations in individual results are so great that they do not fall in any well-defined line. The reason for apparent inconsistencies is to be looked for either in the methods employed, or in actual variations in the performance of the boiler. The methods employed were the same for all tests, while the condition of the boiler was necessarily subject to change. The boiler had to be frequently washed. It is conceivable that dryer steam may be furnished by the boiler when newly washed than when in a condition requiring washing, though there is nothing in the data either to sustain or to discredit such a conclusion. It has, however, been shown by Professor Jacobus that almost all moisture which may be intermixed with steam passing a horizontal pipe separates itself from the steam by gravitation, and forms a rill in the bottom of the pipe, the steam above being approximately dry. Experiments by the writer, involving a visual examination of the steam space of a boiler while in action, revealed no haze or mist above the surface of the water,

TABLE III.

Quality of Steam and Equivalent Evaporation.

THE SEVERAL TESTS REPRESENTED IN THIS TABLE ARE ARRANGED IN ORDER OF THE RATE OF EVAPORATION, NO. 1 REPRESENTING THE TEST FOR WHICH THE RATE IS LEAST, AND NO. 35 THAT FOR WHICH IT IS GREATEST.

Identification of Test.			Duration of Tests in Minutes.	Results of Calorimeter Tests.		Equivalent Evaporation from and at 212 Degrees Fahr. per Hour.	
Consecutive Number.	Laboratory Designation.	Date of Test.		Quality of Steam in Dome of Boiler, Dry Saturated Steam being taken as Unity.	Percentage of Moisture in Steam.	Assuming Quality of Steam as Shown by Column 16.	Assuming all Water Delivered to Boiler to have been Completely Evaporated into Dry Steam.
1	2	3	4	16	17	18	19
1.....	15—1—*A*	Dec. 12, 1894	240	.9951	0.49	6,659	6,683
2.....	15—1b—*V*	Nov. 23, 1894	190	.9937	0.63	6,763	6,794
3.....	15—1—*H*	Dec. 9, 1896	180	.9838	1.62	7,249	7,337
4.....	25—1—*A*	Dec. 14, 1894	255	.9922	0.78	7,318	7,360
5.....	15—1—*G*	Nov. 9, 1896	180	.9894	1.06	7,476	7,535
6.....	15—2—*A*	Nov. 13, 1895	180	.9924	0.76	8,745	8,796
7.....	25—1—*V*	Nov. 26, 1894	240	.9932	0.68	8,865	8,910
8.....	35—1—*A*	Dec. 17, 1894	180	.9917	0.83	9,771	9,832
9.....	35—2—*F*	Jan. 21, 1895	180	.9900	1.00	9,785	9,855
10.....	35—1—*V*	Dec. 7, 1894	140	.9937	0.63	10,284	10,332
11.....	35—2—*E*	Jan. 16, 1895	180	.9932	0.68	10,324	10,377
12.....	45—1—*A*	Nov. 20, 1895	150	.9913	0.87	10,395	10,463
13.....	35—2—*B*	Jan. 14, 1895	170	.9931	0.69	10,414	10,467
14.....	55—1—*A*	Nov. 25, 1895	120	.9878	1.22	10,691	10,788
15.....	35—1—*H*	Dec. 18, 1896	160	.9851	1.49	11,090	11,214
16.....	35—1—*G*	Nov. 20, 1896	170	.9886	1.14	11,226	11,322
17.....	35—1b—*G*	Dec. 2, 1896	170	.9860	1.40	11,312	11,430
18.....	25—2—*A*	Oct. 25, 1895	180	.9910	0.90	11,554	11,633
19.....	55—1—*V*	Dec. 18, 1895	120	.9912	.88	11,624	11,700
20.....	35—2b—*H*	Feb. 10, 1897	160	.9880	1.20	11,634	11,737
21.....	55—1—*H*	Feb. 11, 1897	120	.9871	1.29	12,303	12,422
22.....	55—1—*G*	Nov. 23, 1896	120	.9860	1.31	12,426	12,548
23.....	15—9—*A*	Nov. 6, 1896	150	.9906	0.94	13,670	13,766
24.....	15—9—*H*	Dec. 11, 1896	180	.9871	1.29	13,722	13,853
25.....	35—2—*A*	Dec. 19, 1894	180	.9894	1.06	13,735	13,843
26.....	35—3—*G*	Dec. 4, 1896	140	.9838	1.62	13,867	14,035
27.....	15—9—*G*	Nov. 12, 1896	160	.9871	1.29	13,869	14,002
28.....	35—3—*H*	Dec. 14, 1896	120	.9873	1.27	13,995	14,128
29.....	35—2—*G*	Nov. 13, 1896	160	.9856	1.44	14,725	14,884
30.....	35—2—*H*	Dec. 16, 1896	120	.9866	1.34	14,771	14,932
31.....	45—2—*A*	Nov. 18, 1895	140	.9876	1.24	14,926	15,065
32.....	25—3—*A*	Nov. 1, 1895	122.5	.9889	1.11	15,515	15,644
33.....	35—2—*C*	Jan. 23, 1895	120	.9930	0.70	15,709	15,788
34.....	55—2—*A*	Nov. 22, 1895	68	.9887	1.13	16,773	16,903
35.....	35—3—*A*	Nov. 15, 1895	120	.9889	1.11	17,883	18,032

thus sustaining the conclusion that the steam within the steam space of the boiler is ordinarily dry and saturated; the water is present as water and the steam as steam. They are not intermixed. If this is true, the steam which passes the throttle of a locomotive should be expected to be dry, and it would be entirely so if it were not that the violence of the circulation projects small beads of water upward, far beyond the general surface. Some of these enter the throttle with the steam. This

action explains why the moisture increases with the power of the boiler, and makes it not unreasonable to assume that the purity of the water in the boiler may actually affect the quality of the steam.

The comparative dryness of the steam under all conditions is a fact worthy of emphasis, for the locomotive is often credited with carrying over a great deal of water to the cylinders. The tests show that this does not happen under constant conditions of running. When it occurs it is probably the result of too high a water level or of a sudden demand upon the boiler. For example, if the throttle of a locomotive, which has been for some time inactive, is quickly opened, large volumes of steam bubbles leave the heating surface and crowd to the upper part of the boiler, making spray in the dome, a portion of which may pass out with the steam. A similar action occurs when an engine which has been working at a light load is suddenly required to increase its power. But these are exceptional conditions. Under uniform conditions of running, such as prevailed throughout the tests herein presented, the moisture passing the throttle is never great.

If, as the writer believes, it is fair to conclude that variations in moisture are largely due to incidental conditions, no serious mistake would be made if the indications of the calorimeter were entirely disregarded, and all calculations based on the assumption that the steam generated is dry and saturated. Results thus obtained should be somewhat more consistent, one with another, than those corrected for moisture, and hence for general purposes more satisfactory. In accord with this view, while none of the calorimeter work has been ignored in calculating results, many of the derived results have been carried out in duplicate. Thus the equivalent evaporation is first determined on the assumption that the steam has the quality shown by the calorimeter (column 18), and is also determined on the assumption that all water delivered to the boiler is evaporated into dry and saturated steam (column 19). In accord with the usual practice, however, comparisons which follow are based on the corrected results (column 18).

Power of Boiler (Table IV.).—The power developed by the boiler is proportional to the rate of evaporation (column 18). A few comparisons will serve to show something of the peculiar conditions under which the boiler of a locomotive performs its

service. Thus the water evaporated per foot of grate surface (column 20) varies from less than 400 to more than 1,000 pounds per hour. These figures reflect well the intensity of the furnace action, which must provide for the combustion of sufficient fuel to produce such a result. Similarly the weight of water evaporated per square foot of heating surface (column 21) varies from 5½ to almost 15 pounds per hour, the maximum rate being nearly the equivalent of a boiler horse-power for every 2 square feet of heating surface in the boiler. The total boiler horse-power (column 22), the horse-power per square foot of heating surface

TABLE IV.

POWER.

THE SEVERAL TESTS REPRESENTED IN THIS TABLE ARE ARRANGED IN ORDER OF THE RATE OF EVAPORATION, NO. 1 REPRESENTING THE TEST FOR WHICH THE RATE IS LEAST, AND NO. 35 THAT FOR WHICH IT IS GREATEST.

Identification of Test.			Duration of Test in Minutes.	Equivalent Evaporation from and at 212° Fahr. Pounds, assuming Quality of Steam as shown by Column 16.			Rated Horse-power 34.5 Evaporation Units, assuming Quality of Steam as shown by Column 16.		
Consecutive Numbers.	Laboratory Designation.	Date of Test.		Water per Hour.	Water evaporated per Sq. Ft. of Grate Surface per Hour.	Water evaporated per Sq. Ft. of Heating Surface per Hour.	Total.	Per Sq. Ft. of Heating Surface.	Per Sq. Ft. of Grate Surface.
1	2	3	4	18	20	21	22	23	24
1..	15—1—*A*	Dec. 12, 1894	240	6,659	386	5.48	193	.159	11.2
2..	15—1½—*V*	Nov. 23, 1894	190	6,763	392	5.57	196	.161	11.4
3..	15—1—*H*	Dec. 9, 1896	180	7,249	420	5.97	210	.173	12.2
4..	25—1—*A*	Dec. 14, 1894	255	7,318	424	6.03	212	.175	12.3
5..	15—1—*G*	Nov. 9, 1896	180	7,476	433	6.16	217	.179	12.6
6..	15—2—*A*	Nov. 13, 1895	180	8,745	507	7.20	253	.208	14.7
7..	25—1—*V*	Nov. 26, 1894	240	8,865	514	7.30	257	.212	14.8
8..	35—1—*A*	Dec. 17, 1894	180	9,771	566	8.05	283	.233	16.4
9..	35—2—*F*	Jan. 21, 1895	180	9,785	567	8.06	284	.234	16.4
10..	35—1—*V*	Dec. 7, 1894	140	10,284	596	8.47	298	.245	17.3
11..	35—2—*E*	Jan. 16, 1895	180	10,334	598	8.51	299	.246	17.3
12..	45—1—*A*	Nov. 20, 1895	150	10,395	603	8.56	301	.248	17.4
13..	35—2—*B*	Jan. 14, 1895	170	10,413	604	8.57	302	.249	17.5
14..	55—1—*A*	Nov. 25, 1895	120	10,691	619	8.80	310	.255	17.9
15..	35—1—*H*	Dec. 18, 1896	160	11,090	643	9.13	321	.264	18.6
16..	35—1—*G*	Nov. 20, 1896	170	11,226	650	9.24	325	.268	18.8
17..	35—1½—*G*	Dec. 2, 1896	170	11,312	655	9.31	328	.270	19.0
18..	25—2—*A*	Oct. 25, 1895	180	11,554	669	9.51	335	.276	19.4
19..	55—1—*V*	Dec. 18, 1895	120	11,624	673	9.57	337	.278	19.5
20..	35—2½—*H*	Feb. 10, 1897	160	11,634	674	9.58	337	.278	19.5
21..	55—1—*H*	Feb. 11, 1897	120	12,303	713	10.13	357	.294	20.7
22..	55—1—*G*	Nov. 23, 1896	120	12,426	720	10.23	360	.296	20.9
23..	15—9—*A*	Nov. 6, 1896	150	13,670	792	11.25	396	.326	22.9
24..	15—9—*H*	Dec, 11, 1896	180	13,722	796	11.29	398	.328	23.1
25..	35—2—*A*	Dec. 19, 1894	180	13,735	796	11.31	398	.328	23.1
26..	35—3—*G*	Dec. 4, 1896	140	13,867	804	11.42	402	.331	23.3
27..	15—9—*G*	Nov. 12, 1896	160	13,869	804	11.42	402	.331	23.3
28..	35—3—*H*	Dec. 14, 1896	120	13,995	811	11.52	406	.334	23.5
29..	35—2—*G*	Nov. 13, 1896	160	14,725	853	12.12	427	.352	24.8
30..	35—2—*H*	Dec. 16, 1896	120	14,771	856	12.16	428	.353	24.8
31..	45—2—*A*	Nov. 18, 1895	140	14,926	865	12.29	433	.357	25.1
32..	25—3—*A*	Nov. 1, 1895	122.5	15,515	899	12.77	450	.370	26.1
33..	35—2—*C*	Jan. 23, 1895	120	15,709	911	12.93	455	.375	26.4
34..	55—2—*A*	Nov. 22, 1895	68	16,773	973	13.81	486	.400	28.2
35..	35—3—*A*	Nov. 15, 1895	120	17,883	1,037	14.93	518	.427	30.0

(column 23), and the horse-power per square foot of grate surface (column 26) are also of interest, especially for the higher power tests.

Coal and Combustible (Table V.).—Attention has been called to the very large amount of water evaporated by the boiler tested. It follows that a correspondingly large amount of fuel is needed to bring about this evaporation. The record appears in Table V.

The coal used for all tests was Indiana block, mined in the neighborhood of Brazil. It burns to a white ash without clinkers and is light and friable. These latter qualities prevent its giving maximum results in locomotive service. The composition of several representative samples proved to be as follows:

	1	2	3	4
Per cent. fixed carbon.....	49.65	51.84	51.09	51.59
Per cent. volatile matter.....	40.29	39.00	38.93	38.87
Per cent. combined moisture.....	3.15	3.62	2.35	3.44
Per cent. ash.....	6.91	5.54	7.63	6.10
	100.00	100.00	100.00	100.00

In each test the coal was weighed—a barrowful at a time—as it was dumped at the feet of the fireman. A sample of from 50 to 100 pounds was put into a large galvanized iron pan, and air dried. From results thus obtained, the total weight of coal fired was corrected for accidental moisture, giving results which appear in column 27. As the coal was stored under roof, the correction was always small.

The total weight of dry coal fired, as given for the several tests (column 27) contains two variables—the length of the test and the rate of combustion. The values given as dry coal fired per hour (column 30) eliminate the first variable, and supply a true basis from which to compare the rates of combustion incident to the several tests. It will be seen that the amount of coal fired per hour is between the limits of 729 pounds and 3,133 pounds. Five tests have a rate of less than ½ a ton per hour, and twelve have a greater rate than 1 ton per hour. The rate per square foot of grate per hour (column 32) ranges from 49 to 182, values of which the significance appears when it is considered that even in naval service, under forced draught, the rate seldom exceeds 60 pounds per hour. The coal burned per foot of heating surface per hour (column 33) varies from .7 to 2.6 pounds.

The amount of refuse caught in the ash-pan (column 28) is an item of no great importance in the case of locomotive boilers, since a large amount of non-combustible material which would, under the conditions of stationary practice, lodge in the ash-pan is, in locomotive service, thrown out at the top of the stack. The proportion of the whole amount of ash contained by the fuel which appears in the ash-pan depends upon the force of the draught, or, in other words, upon the rate of power at which

TABLE V.

COAL AND COMBUSTION.

THE SEVERAL TESTS REPRESENTED IN THIS TABLE ARE ARRANGED IN ORDER OF THE RATE OF EVAPORATION, NO. 1 REPRESENTING THE TEST FOR WHICH THE RATE IS LEAST, AND NO. 35 THAT FOR WHICH IT IS GREATEST.

Identification of Test.			Duration of Test in Minutes.	Fuel. Indiana Brazil Block Coal. Pounds.					Rate of Combustion.	
Consecutive Number.	Laboratory Designation.	Date of Test.		Total Dry Coal Fired.	Total Refuse Caught in Ash-pan.	Total Combustible by Analysis.	Dry Coal Fired per Hour.	Combustible Fired per Hour.	Dry Coal Fired per Sq. Ft. of Grate Surface per Hour.	Dry Coal Fired per Sq. Ft. of Heating Surface per Hour.
1	2	3	4	27	28	29	30	31	32	33
1....	15—1—*A*	Dec. 12, 1894	240	3,399	292	3,059	850	765	49.3	.700
2....	15—1b—*V*	Nov. 23, 1894	190	2,577	261	2,319	814	732	47.2	.670
3....	15—1—*H*	Dec. 9, 1896	180	2,375	240	2,138	792	713	45.9	.652
4....	25—1—*A*	Dec. 14, 1894	255	3,864	93	3,478	909	818	52.8	.748
5....	15—1—*G*	Nov. 9, 1896	180	2,678	262	2,410	893	803	51.8	.735
6....	15—2—*A*	Nov. 13, 1895	180	3,297	258	2,967	1,099	989	63.7	.905
7....	25—1—*V*	Nov. 26, 1894	240	4,460	320	4,014	1,115	1,003	64.6	.918
8....	35—1—*A*	Dec. 17, 1894	180	3,785	299	3,406	1,262	1,135	73.1	1.038
9....	35—2—*F*	Jan. 21, 1895	180	3,859	295	3,473	1,286	1,158	74.6	1.059
10....	35—1—*V*	Dec. 7, 1894	140	3,180	272	2,862	1,363	1,227	78.9	1.122
11....	35—2—*E*	Jan. 16, 1895	180	4,107	353	3,696	1,369	1,232	79.3	1.127
12....	45—1—*A*	Nov. 20, 1895	150	3,272	231	2,945	1,309	1,178	75.9	1.078
13....	35—2—*B*	Jan. 14, 1895	170	4,370	461	3,933	1,542	1,388	89.4	1.270
14....	55—1—*A*	Nov. 25, 1895	120	2,980	220	2,682	1,490	1,341	86.4	1.227
15....	35—1—*H*	Dec. 18, 1896	160	4,152	320	3,737	1,557	1,401	90.3	1.283
16....	35—1—*G*	Nov. 20, 1896	170	4,288	342	3,859	1,513	1,362	87.7	1.246
17....	35—1b—*G*	Dec. 2, 1896	170	4,150	380	3,735	1,465	1,318	84.9	1.206
18....	25—2—*A*	Oct. 25, 1895	180	4,826	25	4,343	1,609	1,448	93.3	1.324
19....	55—1—*V*	Dec. 18, 1895	120	3,330	339	2,997	1,665	1,498	96.5	1.371
20....	35—2b—*H*	Feb. 10, 1897	160	4,321	332	3,889	1,620	1,458	93.9	1.334
21....	55—1—*H*	Feb. 11, 1897	120	3,203	214	2,883	1,602	1,441	92.8	1.319
22....	55—1—*G*	Nov. 23, 1896	120	3,769	241	3,392	1,885	1,696	109.2	1.552
23....	15—9—*A*	Nov. 6, 1896	150	5,014	265	4,513	2,006	1,805	116.3	1.651
24....	15—9—*H*	Dec. 11, 1896	180	6,363	344	5,727	2,121	1,909	123.0	1.746
25....	35—2—*A*	Dec. 19, 1894	180	5,933	258	5,339	1,978	1,780	114.6	1.628
26....	35—3—*G*	Dec. 4, 1896	140	4,708	365	4,237	2,018	1,816	117.0	1.662
27....	15—9—*G*	Nov. 12, 1896	160	5,487	354	4,938	2,058	1,852	199.3	1.694
28....	35—3—*H*	Dec. 14, 1896	120	4,248	346	3,823	2,124	1,912	123.2	1.749
29....	35—2—*G*	Nov. 13, 1896	160	6,183	368	5,565	2,319	2,087	134.4	1.909
30....	35—2—*H*	Dec. 16, 1896	120	4,250	297	3,823	2,125	1,912	123.2	1.750
31....	45—2—*A*	Nov. 18, 1895	140	5,720	243	5,148	2,452	2,206	142.1	2.019
32....	25—3—*A*	Nov. 1, 1895	122.5	4,684	91	4,216	2,294	2,065	133.0	1.889
33....	35—2—*C*	Jan. 23, 1895	120	5,356	384	4,820	2,678	2,410	155.3	2.205
34....	55—2—*A*	Nov. 22, 1895	68	2,995	205	2,643	2,695	2,378	153.2	2.176
35....	35—3—*A*	Nov. 15, 1895	120	6,296	298	5,629	3,133	2,819	181.6	2.581

the boiler is worked. It is greatest when the rate of combustion is least. When the engine is worked at very high power, the amount of refuse in the ash-pan—with the light fuel employed in the tests under consideration—is almost negligible.

In stationary practice the total combustible (column 29) is obtained by subtracting the weight of refuse from the weight of coal. For reasons already explained, such a process gives no useful result when applied to the tests of locomotive practice. For the present purpose, therefore, resort has been had to the chemical analysis of the fuel, which shows about one-tenth the weight of the dry coal to be non-combustible. The total combustible is therefore assumed to equal nine-tenths of the weight of dry coal fired. The combustible per hour on this basis is shown as column 31.

Thermal Units (Table VI.).—The thermal units imparted to each pound of water passing the boiler, or

$$Q = xr + q - q_0,$$

is given in column 34. The rate at which heat is transferred, as indicated by the thermal units absorbed by the water of the boiler each minute, is given in column 35, while the thermal units absorbed per pound of dry coal burned are given in column 36, and per pound of combustible in column 37.

No attempt has been made to express in numerical terms the thermal efficiency of the boiler. The determination of such a value depends upon the heating value of the fuel, which is not known in precise terms. It is probably not far from 13,000 thermal units per pound of dry coal. Comparing this value with the number of thermal units taken up by the water of the boiler for each pound of coal burned (column 36), an approximate estimate of the thermal efficiency of the boiler may be had.

While the facts presented by this table are especially for the convenience of those who may desire to compare the performance of the boiler tested with data from other boilers, they are not without interest in themselves. For example, it is of interest to see that in test No. 35 the boiler transmitted approximately 288,000 thermal units per minute. That is, it delivered heat sufficient to raise the temperature of 144 tons of water one degree every minute. As many locomotives are now in service having more than double the power of the one tested, it may be said that the modern locomotive is capable of delivering sufficient

TABLE VI.

THERMAL UNITS.

THE SEVERAL TESTS REPRESENTED IN THIS TABLE ARE ARRANGED IN ORDER OF THE RATE OF EVAPORATION, NO. 1 REPRESENTING THE TEST FOR WHICH THE RATE IS LEAST, AND NO. 35 THAT FOR WHICH IT IS GREATEST.

Identification of Test.			Duration of Test in Minutes.	British Thermal Units. Assuming Steam to have the Quality as shown by Column 16.			
Consecutive Number.	Laboratory Designation.	Date of Test.		Per Pound of Steam Generated.	Total per Minute.	Per Pound of Dry Coal.	Per Pound of Combustible.
1	2	3	4	34	35	36	37
1.....	15—1—*A*	Dec. 12, 1894	240	1,164.1	107,194	7,569	8,410
2.....	15—1[b]—*V*	Nov. 23, 1894	190	1,162.6	108,858	8,026	8,918
3.....	15—1—*H*	Dec. 9, 1896	180	1,152.4	116,668	8,842	9,823
4.....	25—1—*A*	Dec. 14, 1894	255	1,160.0	117,798	7,774	8,638
5.....	15—1—*G*	Nov. 9, 1896	180	1,158.6	120,340	8,088	8,988
6.....	15—2—*A*	Nov. 13, 1895	180	1,160.2	140,778	7,686	8,541
7.....	25—1—*V*	Nov. 26, 1894	240	1,161.8	142,688	7,678	8,531
8.....	35—1—*A*	Dec. 17, 1894	180	1 161.7	157,268	7,479	8,310
9.....	35—2—*F*	Jan. 21, 1895	180	1,165.1	157,502	7,348	8,163
10.....	35—1—*V*	Dec. 7, 1894	140	1,164.7	165,546	7,288	8,098
11.....	35—2—*E*	Jan. 16, 1895	180	1,164.1	166,188	7,283	8,093
12.....	45—1—*A*	Nov. 20, 1895	150	1,158.1	167,336	7,671	8,523
13.....	35—2—*B*	Jan. 14, 1895	170	1,160.5	167,624	6,521	7,245
14.....	55—1—*A*	Nov. 25, 1895	120	1,154.7	172,079	6,729	7,699
15.....	35—1—*H*	Dec. 18, 1896	160	1,155.3	178,516	6,879	7,643
16.....	35—1—*G*	Nov. 20, 1896	170	1,156.5	180,706	7,164	7,961
17.....	35—1[b]—*G*	Dec. 2, 1896	170	1,157.4	182,072	7,458	8,287
18.....	25—2—*A*	Oct. 25, 1895	180	1,158.2	185,994	6,937	7,709
19.....	55—1—*V*	Dec. 18, 1895	120	1,156.3	187,109	6,743	7,492
20.....	35—2[b]—*H*	Feb. 10, 1897	160	1,160.0	187,360	6,934	7,704
21.....	55—1—*H*	Feb. 11, 1897	120	1,158.5	198,046	7,419	8,243
22.....	55—1—*G*	Nov. 23, 1896	120	1,156.1	200,015	6,369	7,076
23.....	15—9—*A*	Nov. 6, 1896	150	1,157.2	220,038	6,583	7,314
24.....	15—9—*H*	Dec. 11, 1896	180	1 156.6	220,866	6,248	6,942
25.....	35—2—*A*	Dec. 19, 1894	180	1,159.3	221,072	6,707	7,452
26.....	35—3—*G*	Dec. 4, 1896	140	1,154.8	223,206	6,637	7,375
27.....	15—9—*G*	Nov. 12, 1896	160	1,157.0	223,243	6,510	7,234
28.....	35—3—*H*	Dec. 14, 1896	120	1,155.9	225,366	6,363	7,071
29.....	35—2—*G*	Nov. 13, 1896	160	1,154.6	237,025	6,134	6,815
30.....	35—2—*H*	Dec. 16, 1896	120	1,153.5	237,746	6,713	7,459
31.....	45—2—*A*	Nov. 18, 1895	140	1,155.9	240,262	5,881	6,534
32.....	25—3—*A*	Nov. 1, 1895	122	1,158.8	249,743	6,531	7,256
33.....	35—2—*C*	Jan. 23, 1895	120	1,166.7	252,873	5,666	6,296
34.....	55—2—*A*	Nov. 22, 1895	68	1,153.9	269,996	6,130	6,812
35.....	35—3—*A*	Nov. 15, 1895	120	1,156.3	287,871	5,513	6,126

heat to raise 300 tons of water one degree in temperature each minute.

Draught, Rate of Combustion, and Smoke-box Temperature (Table VII.).—For the present purpose, draught is defined as the difference between the pressure of the atmosphere and that of the smoke-box. The draught-gauge consists of a U-tube, partially filled with water and securely attached to a column of the laboratory. One leg of the tube is in pipe connection with the interior of the smoke-box, the opening being at the point C, Fig. 152, and on the axis of the boiler. Observations were made

at five-minute intervals. For the tests reported, the average draught (column 38) varies from 1.7 inches to 7.5 inches.

In any boiler the condition of draught determines the rate of combustion, and consequently, under ideal conditions, the draught will be a function of the rate of combustion. But under conditions actually affecting the action of the boiler of a locomotive there are variations in this relationship. The precise action of the steam jet in producing a draught action has been discussed in another place.* It is shown elsewhere in this

TABLE VII.

DRAUGHT, RATE OF COMBUSTION, AND SMOKE-BOX TEMPERATURE.

THE SEVERAL TESTS REPRESENTED IN THIS TABLE ARE ARRANGED IN ORDER OF THE RATE OF EVAPORATION, NO. 1 REPRESENTING THE TEST FOR WHICH THE RATE IS LEAST, AND NO. 35 THAT FOR WHICH IT IS GREATEST.

Identification of Test.			Duration of Test in Minutes.	Average Pressure. Draught, or Vacuum, in Smoke-box. Inches of Water.	Average Temp., Deg., Fahr., of Smoke-box.	Fuel: Indiana Brazil Block Coal, Pounds. Dry Coal Fired per Hour.
Consecutive Number.	Laboratory Designation.	Date of Test.				
1	2	3	4	38	39	40
1	15—1—*A*	Dec. 12, 1894	240	1.72	553	850
2	15—1[b]—*V*	Nov. 23, 1894	190	2.04	550	814
3	15—1—*H*	Dec. 9, 1896	180	1.93	570	792
4	25—1—*A*	Dec. 14, 1894	235	1.93	567	909
5	15—1—*G*	Nov. 9, 1896	180	1.87	583	893
6	15—2—*A*	Nov. 13, 1895	180	2.42	621	1,099
7	25—1—*V*	Nov. 26, 1894	240	2.60	606	1,115
8	35—1—*A*	Dec. 17, 1894	180	3.00	628	1,262
9	35—2—*F*	Jan. 21, 1895	180	2.57	653	1,286
10	35—1—*V*	Dec. 7, 1894	140	3.43	633	1,363
11	35—2—*E*	Jan. 16, 1895	180	2.89	652	1,369
12	45—1—*A*	Nov. 20, 1895	150	2.68	644	1,309
13	35—2—*B*	Jan. 14, 1895	170	3.28	664	1,542
14	55—1—*A*	Nov. 25, 1895	120	2.58	675	1,490
15	35—1—*H*	Dec. 18, 1896	160	3.00	655	1,557
16	35—1—*G*	Nov. 20, 1896	170	3.02	685	1,513
17	35—1[b]—*G*	Dec. 2, 1896	170	2.98	618	1,465
18	25—2—*A*	Oct. 25, 1895	180	3.37	696	1,609
19	55—1—*V*	Dec. 18, 1895	120	3.20	667	1,665
20	35—2[b]—*H*	Feb. 10, 1897	160	3.18	689	1,620
21	55[2]—1—*H*	Feb. 11, 1897	120	3.44	695	1,602
22	55—1—*G*	Nov. 23, 1896	120	3.57	....	1,885
23	15—9—*A*	Nov. 6, 1896	150	4.56	734	2,006
24	15—9—*H*	Dec. 11, 1896	180	4.99	696	2,121
25	35—2—*A*	Dec. 19, 1894	180	4.42	720	1,978
26	35—3—*G*	Dec. 4, 1896	140	4.88	719	2,018
27	15—9—*G*	Nov. 12, 1896	160	4.76	724	2,058
28	35—3—*H*	Dec. 14, 1896	120	4.52	....	2,124
29	35—2—*G*	Nov. 13, 1896	160	4.65	655	2,319
30	35—2—*H*	Dec. 16, 1896	120	4.33	....	2,125
31	45—2—*A*	Nov. 18, 1895	140	4.93	741	2,452
32	25—3—*A*	Nov. 1, 1895	122.5	5.45	762	2,204
33	35—2—*C*	Jan. 23, 1895	120	5.13	738	2,678
34	55—2—*A*	Nov. 22, 1895	68	4.58	755	2,695
35	35—3—*A*	Nov. 15, 1895	120	7.48	798	3,133

* Report of Committee on "Exhaust Pipes and Steam Passages." *Proceedings of the American Railway Master Mechanics' Association*, 1896.

paper that, other things being equal, the capacity of the jet as a means for producing draught is nearly proportional to the weight of steam discharged per unit of time; that, whether the discharge is in the slow, heavy puffs incident to slow speed, or in lighter but more rapid impulses, is not material. If the weight of steam discharged is the same, the draught action is approximately constant. The reduction of pressure in the smoke-box, however, which may result from the action of the exhaust under given conditions, depends upon the freedom with which air is permitted to pass into the fire-box. If the fire is thick and solid, the draught, as determined by the reduction of pressure in the smoke-box, will be high; if the fire is light, the draught will be low. This is well shown by Fig. 154, which is a representative diagram from the registering vacuum-gauge connected with the smoke-box. The normal draught is indicated by the line *a*, *b*, and *c*. When the fire door is opened the draught drops, though the scale at which Fig. 154 is reproduced does not permit this to be well shown. When the ash-pan dampers are closed the draught goes up to the points *d* and *e*. The draught readings given (column 38) are the average results of operations at five-minute intervals. They may be accepted as a close approximation to the normal readings for the tests.

The relation of reduction of pressure in the smoke-box to coal burned per square foot of grate surface is well shown by Fig. 156, and the relation of pressure reduction in smoke-box and evaporation per square foot of heating surface by Fig. 157. The first diagram (Fig. 156) represents the effect of changes in the draught condition on combustion, and the second (Fig. 157) upon the evaporative power of the boiler. In both diagrams, for reasons already in part explained, the points representing individual tests fall irregularly. An approximation to the mean curve, representing draught and rate of combustion, is shown by the straight line (Fig. 6) which is represented by the equation,

$$D = .037G \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which D is the draught in inches of water, and G is the pounds of coal per square foot of grate per hour.

Smoke-box temperatures were determined by the use of a copper ball of known weight which was lodged in the centre of the smoke-box (*B*, Fig. 152) until its temperature had become equal to that of the surrounding gases. It was then allowed to

roll quickly down an inclosed tube into a water calorimeter, the original temperature of the ball being calculated from data thus obtained. By these means it was possible ordinarily to obtain one observation for each hour's duration of test. For

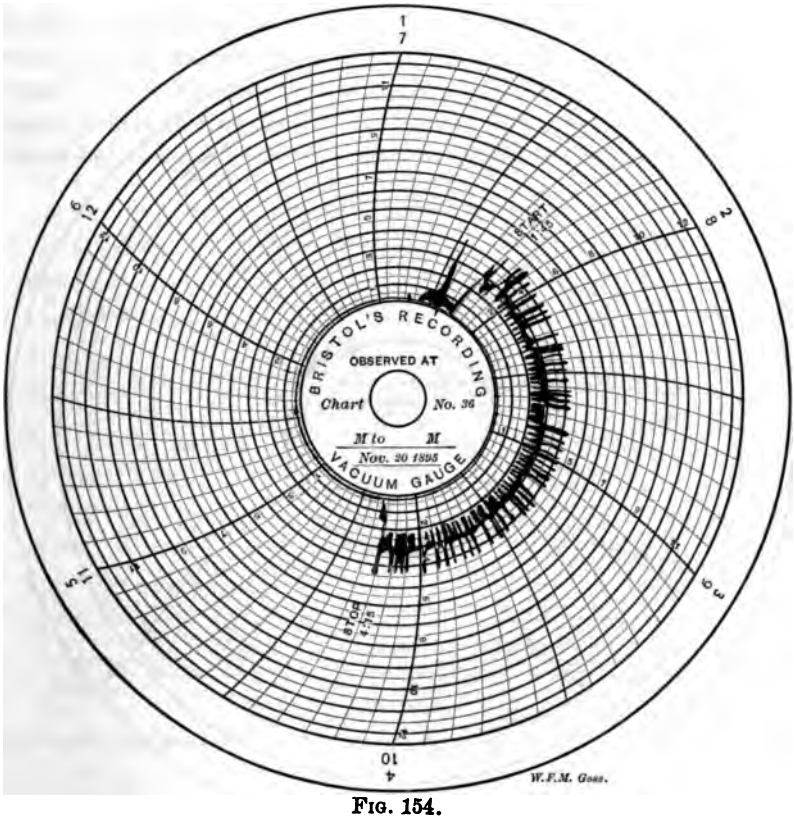

FIG. 154.

CHART FROM RECORDING GAUGE, SHOWING DRAUGHT.

This and other charts from recording gauges are from test No. 12. The test began with a flying start at 1.45. The normal draught from the test was a little less than 3 inches (exactly 2.68 inches). Where the line rises above this valve it indicates that the dampers were closed, and where it falls below, that the fire-door was open. So far as the record shows the frequency with which the dampers were changed, the record is an unusual one. Referring to the diagrams of other gauges (Figs. 153 and 155), the constancy of steam pressure and of draught may be judged.

some of the later tests a Le Chatelier pyrometer was used in connection with the copper ball, and still more recently has been exclusively depended upon, but all of the data presented are from the copper ball calorimeter.

The smoke-box temperature, as affected by changes in the rate

of combustion, is shown by Fig. 156, and as affected by changes in the rate of evaporation by Fig. 157. From these figures it will be seen that as the power of the boiler is increased the smoke-box temperature rises; also that, as in the case of the draught, the points representing individual tests fall irregularly. It should

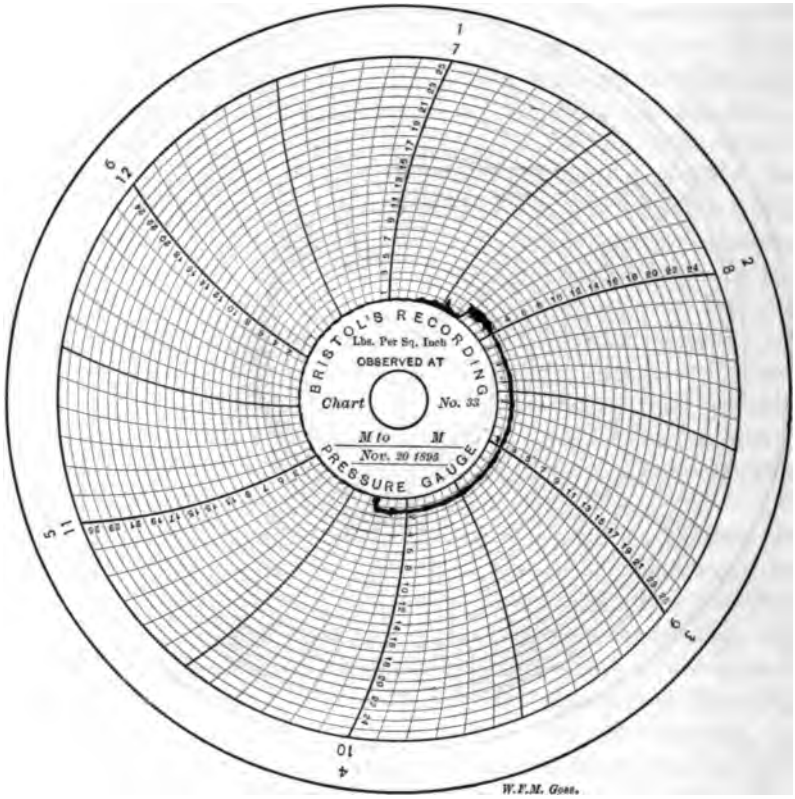

FIG. 155.

CHART FROM RECORDING GAUGE, SHOWING BACK PRESSURE IN EXHAUST PASSAGE OF SADDLE.

be noticed, however, that the smoke-box temperature (column 39) is lower than it is usually assumed to be. It varies from 550 degrees to 798, a range which, considering the variation in the rate of combustion (column 40), is not great. Ideal conditions should make the smoke-box temperature a function of the rate of combustion, but under actual conditions the relationship, as it appears in Fig. 156, is not without variation. This is unquestionably due to differences in fire condition, the efficiency

of the action at the grate varying greatly for different tests. Other things being equal, a low smoke-box temperature should be expected to indicate a thin fire.

Smoke-box temperatures, plotted with evaporation, are given in Fig. 157. As evaporation is more directly a function of the heat passing the tubes than of furnace action, this comparison does not necessarily involve inequalities in the action of the grate. For this reason the points should be expected to fall more nearly in line, but at the scale chosen for the diagram it must be confessed that the actual difference is not great.

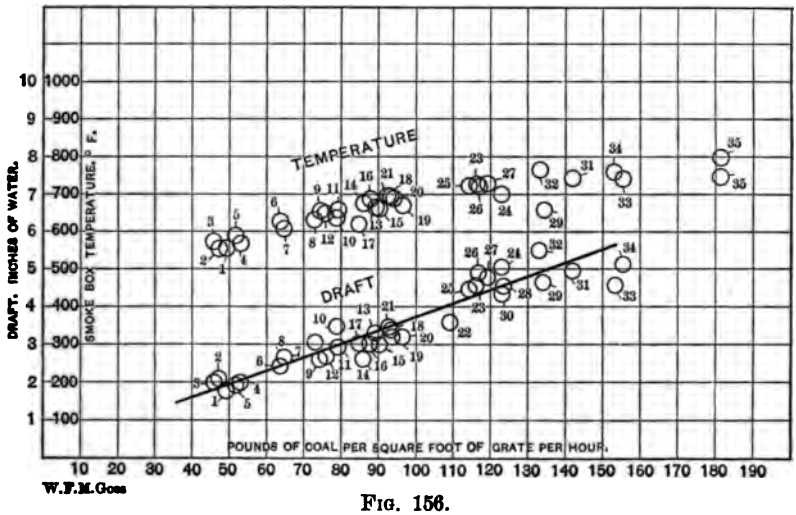

FIG. 156.

POUNDS OF COAL PER FOOT OF GRATE PER HOUR, AS RELATED TO DRAUGHT AND SMOKE-BOX TEMPERATURE.

Evaporative Performance (Table VIII.).—If it is remembered that the results of this, as of other tables, are arranged in order of power the data it presents will have increased significance. For example, by merely scanning its columns, the change in evaporative efficiency resulting from increment power may be seen. The table shows the actual evaporation per pound of dry coal (column 41) to vary from 6½ pounds of water for the lightest power test to 4.77 for the heaviest. Columns 42 and 43 show respectively the evaporation from and at 212 degrees Fahr. for each pound of dry coal, assuming the quality of the steam to be that shown by the calorimeter (column 16), and assuming all steam generated to have been dry and saturated. In a similar

TABLE VIII.

Evaporative Performance.

THE SEVERAL TESTS REPRESENTED IN THIS TABLE ARE ARRANGED IN ORDER OF THE RATE OF EVAPORATION, NO. 1 REPRESENTING THE TEST FOR WHICH THE RATE IS LEAST, AND NO. 35 THAT FOR WHICH IT IS GREATEST.

Consecutive Number.	Identification of Test. Laboratory Designation.	Date of Test.	Duration of Test in Minutes.	Evaporative Performance. Evaporation. Total Water divided by Total Coal.	Equivalent Evaporation from and at 212° Fahr. Per Pound of Dry Coal. Assuming quality of Steam as shown by Column 16.	Per Pound of Dry Coal. Assuming all Water delivered to have been completely evaporated into Dry Steam.	Per Pound of Combustible. Assuming quality of Steam as shown by Column 16.	Per Pound of Combustible. Assuming all Water delivered to have been completely evaporated into Dry Steam.
1	2	3	4	41	42	43	44	45
1...	15—1—*A*	Dec. 12, 1894	240	6.50	7.83	7.86	8.70	8.74
2...	15—1—*V*	Nov. 23, 1894	190	6.90	8.31	8.35	9.24	9.28
3...	15—1—*H*	Dec. 9, 1896	180	7.67	9.15	9.26	10.17	10.29
4...	25—1—*A*	Dec. 14, 1894	255	6.70	8.05	8.10	8.95	9.00
5...	15—1—*G*	Nov. 9, 1896	180	6.98	8.37	8.44	9.31	9.38
6...	15—2—*A*	Nov. 13, 1895	180	6.63	7.95	8.00	8.84	8.89
7...	25—1—*V*	Nov. 26, 1894	240	6.61	7.95	7.99	8.84	8.88
8...	35—1—*A*	Dec. 17, 1894	180	6.44	7.74	7.99	8.61	8.66
9...	35—2—*F*	Jan. 21, 1895	180	6.31	7.61	7.66	8.45	8.51
10...	35—1—*V*	Dec. 7, 1894	140	6.26	7.54	7.58	8.38	8.42
11...	35—2—*E*	Jan. 16, 1895	180	6.26	7.54	7.58	8.38	8.42
12...	45—1—*A*	Nov. 20, 1895	150	6.62	7.96	7.99	8.83	8.88
13...	35—2—*B*	Jan. 14, 1895	170	5.62	6.75	6.79	7.50	7.54
14..	55—1—*A*	Nov. 25, 1895	120	6.00	7.17	7.24	7.95	8.04
15...	35—1—*H*	Dec. 18, 1896	160	5.95	7.12	7.20	7.92	8.00
16...	35—1—*G*	Nov. 20, 1896	170	6.19	7.41	7.48	8.24	8.31
17...	35—1b—*G*	Dec. 2, 1896	170	6.44	7.72	7.80	8.58	8.66
18...	25—2—*A*	Oct. 25, 1895	180	5.99	7.18	7.23	7.98	8.04
19...	55—1—*V*	Dec. 18, 1895	120	5.83	6.98	7.03	7.76	7.81
20...	35—2b—*H*	Feb. 10, 1897	160	5.98	7.18	7.25	7.97	8.05
21...	55—1—*H*	Feb. 11, 1897	120	6.40	7.68	7.75	8.54	8.62
22...	55—1—*G*	Nov. 23, 1896	120	5.51	6.59	6.66	7.33	7.40
23...	15—9—*A*	Nov. 6, 1896	150	5.69	6.81	6.86	7.57	7.63
24...	15—9—*H*	Dec. 11 1896	180	5.40	6.47	6.53	7.18	7.26
25...	35—2—*A*	Dec. 19, 1894	180	5.79	6.94	7.00	7.72	7.78
26...	35—3—*G*	Dec. 4, 1896	140	5.75	6.87	6.95	7.63	7.73
27...	15—9—*G*	Nov. 12, 1896	160	5.63	6.74	6.80	7.49	7.56
28...	35—3—*H*	Dec. 14, 1896	120	5.50	6.59	6.65	7.32	7.39
29...	35—2—*G*	Nov. 13, 1896	160	5.31	6.35	6.42	7.06	7.13
30...	35—2—*H*	Dec. 16, 1896	120	5.82	6.95	7.03	7.73	7.81
31...	15—2—*A*	Nov. 18, 1895	140	5.09	6.09	6.14	6.77	6.83
32...	25—3—*A*	Nov. 1 1895	122.5	5.04	6.76	6.82	7.51	6.57
33...	35—2—*C*	Jan. 23, 1895	120	4.86	5.86	5.90	6.52	6.55
34...	55—2—*A*	Nov. 22, 1895	68	5.31	6.34	6.40	7.04	7.11
35..	35—3—*A*	Nov. 15, 1895	120	4.77	5.71	5.76	6.36	6.39

manner columns 44 and 45 show the equivalent evaporation per pound of combustible, assuming the quality of steam to be that shown by column 16, and assuming the quality to be that of dry saturated steam. All of these values are proportional to the evaporative efficiency of the boiler.

Referring to the equivalent evaporation per pound of coal as it would ordinarily be calculated (column 42), it will be seen that

for the lightest power test the evaporation was 7.83 pounds, and that it is diminished greatly, but somewhat irregularly, as the rate of evaporation increases, until, when the power of the boiler becomes maximum, it is reduced to 5.71, a loss of 27 per cent. The equivalent evaporation per pound of coal for the several tests (column 42) and the rate of evaporation, as represented by the pounds of water evaporated per square foot of heating surface per hour (column 21), are plotted in Fig. 158. From the points of this diagram an effort has been made to locate a curve which

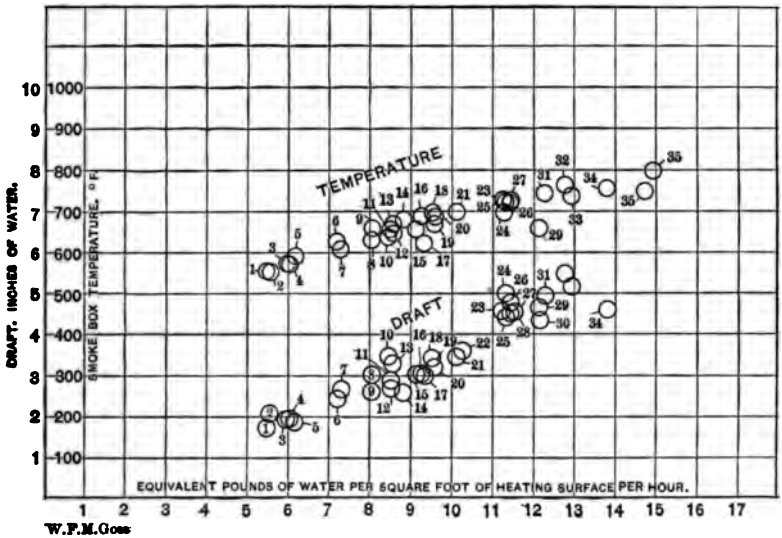

FIG. 157.

POUNDS OF WATER PER FOOT OF HEATING SURFACE PER HOUR, AS RELATED TO DRAUGHT AND SMOKE-BOX TEMPERATURE.

should show the relation of the evaporative efficiency to the rate of evaporation. The method adopted may be described as follows:

The several points were separated into nine groups, those of each group representing tests of nearly the same power. The grouping is as follows:

1st Group.	*2d Group.*	*3d Group.*	*4th Group.*	*5th Group.*
Test 1	Test 6	Test 8	Test 15	Test 21
" 2	" 7	" 9	" 16	" 22
" 3		" 10	" 17	
" 4		" 11	" 18	
" 5		" 12	" 19	
		" 13	" 20	
		" 14		

6th Group.	*7th Group.*	*8th Group.*	*9th Group.*
Test 23	Test 29	Test 34	Test 35
" 24	" 30		
" 25	" 31		
" 26	" 32		
" 27	" 33		
" 28			

The centres of the first seven groups have been determined and their location is shown on the diagram by solid black spots. A straight line drawn as nearly as possible through the points thus located is assumed to show the relationship sought. There are but two centres of groups that are as much as 1 per cent. away from this line, and four touch it within one-tenth of one per cent.

Before attempting a more critical examination of the line thus located, we may inquire why so many of the points representing individual tests and shown upon the diagram by light circles, fall at so great a distance from it. The facts in the case are as follows:

11	points	or	31	per cent.	of	the	whole	agree	with the curve within 1 per cent.
15	"		43	"	"	"	"	"	2 "
18	"		51	"	"	"	"	"	3 "
21	"		60	"	"	"	"	"	4 "
24	"		69	"	"	"	"	"	5 "
27	"		77	"	"	"	"	"	6 "

There is a widespread feeling among motive-power men that the character of the exhaust has much to do with the efficiency of the furnace action; that a heavy exhaust incident to slow running will have a different effect upon the fire than the lighter but more rapid action attending higher speeds, though the draught, as registered by a gauge in the smoke-box, may read the same. It was but natural, therefore, to first look to the engine conditions for an explanation of the irregularities in the efficiency of the boiler. The result of such a study tends to disprove the commonly accepted theory, and justifies the conclusion that, with a given vacuum in the smoke-box, the action of the boiler is quite independent of the manner in which the vacuum is maintained, whether by slow heavy beats or quicker, lighter pulsations. For example, we have tests 1, 2, 3, 4, and 5 for which differences in engine conditions were confined to the dimensions or the setting of the valves. All were run at a speed of 15 miles

an hour and all at shortest cut-off, and yet the results are widely separated. In the second group are tests 6 and 7, which check each other closely, but one was run at low speed under a liberal cut-off (15—2), while the other was at a higher speed and shorter cut-off (25—1). The third group consists of tests 8 (35—1—*A*), 9 (35—2—*F*), 10 (35—1—*V*), 11 (35—2—*E*), 12 (45—1—*A*), 13 (35—2—*B*), and 14 (55—1—*A*). Of tests numbered 8, 9, 10, and 11, all at 35 miles an hour, two were run at short cut-off and two at a more liberal one, but the points of all fall near the curve. Of the fourth group, including tests 15 (35—1—*H*), 16 (35—1—*G*), 17 (35—1_b—*G*), 18 (25—2—*A*), 19 (55—1—*V*), 30 (35—2_b—*H*), tests 16, 18, and 20, which differ one from the other in speed and cut-off, fall most nearly upon the curve, while tests 15 and 16, having the same condition, fall on the opposite side. The two tests of the fifth group, 21 (55—1—*H*), and 22 (55—1—*G*), both at the same high speed and short cut-off, fall on either side of the line curve. A comparison of the remaining groups gives similar results. It seems, therefore, but fair to conclude that variations in the character of the exhaust jet—such as result from changes in speed or cut-off—do not in themselves affect the efficiency of the boiler.

It is well known that, when an engine is working under a light load, a skilful fireman can maintain a very thin fire over the whole grate. Under favorable conditions one may almost see the grate bars through the fire. All portions of such a fire are bright, and there will be plenty of steam, but the firing must be frequent. Such a fire offers so little resistance to the incoming air that larger volumes than are needed for combustion pass through the furnace and absorb a portion of its heat. Again, the fire may be made so thick that it will not burn clear. The demand for steam may not be great, and a sluggish and smoky fire may serve to generate it. But such conditions cannot give maximum efficiency. It follows that somewhere between the very thin fire and the very thick fire will be one of such thickness as will result in maximum efficiency. The same fireman served for all tests here reported. He was skilled in his work, and every effort was made to have a fire suited to the demands made upon it. But the locomotive fireman takes his cue from the steam-gauge rather than from the furnace. If the finger of the gauge is moving upward, or holds its own, the fire is usually assumed to be all right; if it falls, something must be

done. The actual condition of the fire under such circumstances, especially in a test for which a constant speed and load are maintained, depends very much upon the character of the fire at the start. It may happen that two tests, apparently identical as to speed, load, etc., may be run, one with a thick fire and the other with a comparatively thin fire, and, so far as outward conditions are concerned, the tests may seem equally satisfactory, while neither satisfies conditions for maximum efficiency.

With these facts in mind, we may now inquire further con-

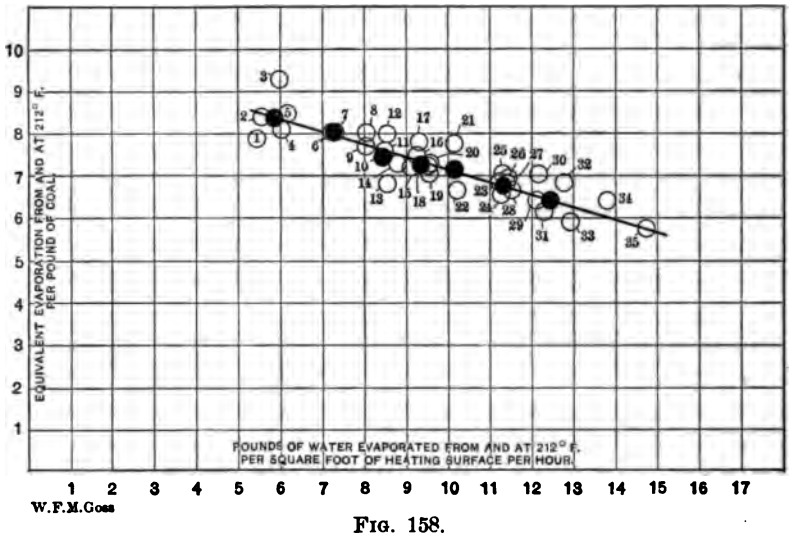
EQUIVALENT EVAPORATION FROM AND AT 212° F. PER POUND OF COAL
POUNDS OF WATER EVAPORATED FROM AND AT 212° F. PER SQUARE FOOT OF HEATING SURFACE PER HOUR.
W.F.M.Goss

FIG. 158.

RATE OF EVAPORATION AND EFFICIENCY, AS SHOWN BY POUNDS OF WATER PER SQUARE FOOT OF HEATING SURFACE PER HOUR AND POUNDS OF WATER PER POUND OF COAL.

cerning the variations in the results of tests to which attention has already been directed. Thus a comparison of the 11 tests that agree with the mean curve (Fig. 158) within 1 per cent. with the 11 tests which have the greatest divergence from it reveals the fact that the tests of the latter class are, for the most part, those in which the firing of the boiler was difficult. The greater part of the tests of this group are either tests at very low power, for which only a light fire could be maintained without danger of losing steam at the safety valve, or tests at high speeds, when the work of firing was hard and difficult. Included in this group also is one test under low boiler-pres-

sure, which is to be regarded as a light power test. On the other hand, those which agree most nearly with the curve are, for the most part, tests at medium load, which were easily fired. An exhibit of these facts is as follows:

Results in Agreement with the Curve.					Results which Diverge from the Curve.				
Distance which Points are Off the Curve.	Test Number.	Laboratory Designation.			Distance which Points are Off the Curve.	Test Number.	Laboratory Designation.		
Per Cent.		Speed.	Cut-off.	Series.	Per Cent.		Speed.	Cut-off.	Series.
0	6	15	2	*A*	10.6	13	35	2	*B*
0.2	35	35	3	*A*	9.9	3	15	1	*H*
0.3	11	35	2	*E*	8.5	21	55	1	*H*
0.4	7	25	1	*V*	7.9	1	15	1	*A*
0.4	10	35	1	*V*	7.4	32	25	3	*A*
0.5	8	35	1	*A*	7.3	30	35	2	*H*
0.7	23	15	9	*A*	6.5	22	55	1	*G*
0.8	27	15	9	*G*	6.2	33	35	2	*C*
0 9	20	35	2_b	*H*	5.8	34	55	2	*A*
0.9	16	35	1	*G*	5.4	31	45	2	*A*
0.9	2	15	1_b	*V*	5.3	12	45	1	*A*

Accepting the experimental results as reliable, it seems safe to conclude that variations in the efficiency of the boiler, as disclosed by different tests at the same power, are due to irregularities in the character of firing.

Power and Efficiency.—Referring again to Fig. 158, it should be noted that the ordinates in this diagram represent the evaporative efficiency of the boiler, and the abscissæ the rate of evaporation. The manner in which the line which is assumed to represent the mean of these points was drawn has already been described. The equation for the line is

$$E = 10.08 - .296H \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

in which E is the pounds of water evaporated from and at 212 degrees Fahr. per pound of coal, and H the pounds evaporated per square foot of heating surface per hour.

This equation and others derived from it are assumed to represent the average performance of the boiler when using Indiana block coal. By its use it is possible to obtain a coal record from the water rate, no weighings being made of the fuel. Defe for such a practice is to be found in the comparative ease with which the water record is obtained, and in the fact that the

consumption, as determined from the equation, is a more consistent factor than can ordinarily be obtained experimentally from a few tests. The form of the equation will doubtless hold for all boilers of similar design with that tested, but the constants may change with the proportions of the boiler, and will of necessity change with the character of the fuel employed.

Efficiency as Affected by the Quality of Fuel:—While apparently somewhat apart from the present purpose, it will be of interest in connection with the general discussion to review certain results which have been obtained from five different samples of fuel tested in the same boiler, and which were reported in a paper presented to the Western Railway Club at the December meeting, 1898. The several samples were designated as *A*, *B*, *C*, *D*, and *E*. All were bituminous coals. The evaporation obtained from each of these samples is shown by Fig. 159. Line *D* on the diagram very nearly corresponds with that given in Fig. 158 for the Indiana block, and its equation is substantially that given above. The equation for line *E*, representing the best coal, may be taken as

$$E_1 = 12.9 - 0.41\ H \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

and for line *C*, representing the poorest coal as

$$E_2 = 9.4 - 0.24\ H \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (b)$$

These equations probably represent the range of variations in performance, as affected by different qualities of fuel.

The rate of evaporation represented by the experiments with the Indiana block, upon which equation 2 is based, lies between the limits of 5 and 15 pounds of water per square foot of heating surface per hour, while the limits on which equations *a* and *b* are based are but little narrower. The equations then are reliable when *H* is allowed a value which is not less than 5 nor greater than 15.

In this connection it is of interest to note that the lines *E*, *A*, *B*, *C*, *D* converge, and it may be assumed that if *D* and *C* were sufficiently extended they would meet; that is, if the rate of evaporation were made sufficiently high, both the good and the poor coal would give the same evaporation. The point where this would happen can be determined from equations *a* and *b* by making E_1 equal to E_2. Thus,

$$12.9 - 0.41\ H = 9.4 - 0.24\ H$$

and

$$H = 20. \text{ approximately.}$$

That is, accepting for the moment this equation as true for all values of H, they show that when the boiler is forced to evaporate 20 pounds of water per square foot of heating surface per hour, the poorer coal will evaporate as much water per pound as the better. It is evident that the equations are not to be relied upon for conditions so widely separated from those covered by the experiments, and it is equally evident that the boiler could not easily be forced to so high a rate of evaporation. The general

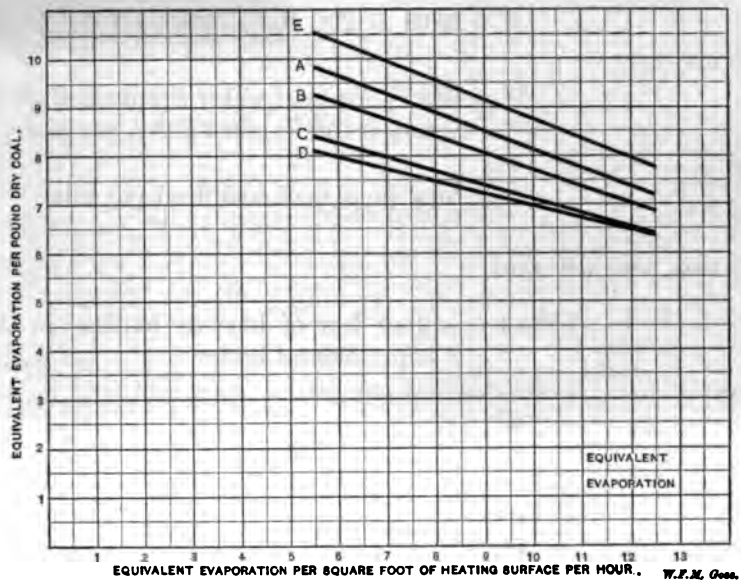

FIG. 159.

RATE OF EVAPORATION AND EFFICIENCY FOR FIVE DIFFERENT SAMPLES OF BITUMINOUS COAL.

conclusion to be deduced is, however, perfectly logical. The higher the power to which a boiler is forced, the smaller is the fraction of the total heat developed which can be absorbed by the heating surface. If forced to very high power, the amount of heat utilized out of all that is available becomes so small that slight variations in the amount available do not measurably affect the amount utilized.

If carried to extreme limits, it will doubtless appear that the line of Fig. 158, represented by equation 2, is in fact not straight, though, within limits which are sufficiently broad to cover all practical cases, it may probably be so considered. The form of

this and of other similar lines is the subject of discussion in a preceding paragraph.

Derived Relations:—The relation between the rate of evaporation and the rate of combustion for the thirty-five tests under discussion is shown by Fig. 160. The points in this figure are located from experimental data, but the curve which is assumed to represent their mean value was plotted from its equation as derived from equation 2. Thus equation 2, as already given, is

$$E = 10.08 - .296\ H. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

We may let

W = total pounds of water evaporated, from and at 212 degrees Fahr. per hour,

and

C = total pounds of coal fired per hour.

We may note also that

1,214.4 = square feet of heating surface in the experimental boiler.

Then

$$\frac{W}{C} = E, \text{ and } H = \frac{W}{1{,}214};$$

or

$$\frac{W}{C} = 10.08 - 0.296\ H$$

$$= 10.08 - \frac{0.266\ W}{1{,}214.4},$$

and

$$C = \frac{W}{10.08 - 0.000244\ W}. \quad . \quad . \quad . \quad . \quad . \quad (3)$$

It is from this equation that the curve (Fig. 160) was plotted. It will be seen that, while the curve is derived quite independently of the points, the two systems agree closely.

The relation of water evaporated per pound of coal and of pounds of coal consumed per square foot of grate per hour is shown by Fig. 161.

This curve, in common with the one preceding, is plotted from its equation, which was obtained as follows:

Having

$$E = 10. \quad - .296\,H, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

let

G = po of coal per square foot of grate r.

Note that

17.25 = sq re feet of grate surface for the ex- imental boiler.

It has already been shown

$$\frac{W}{C} = 10.08 - \frac{0.296}{1{,}214.4}\,W,$$

or

$$\frac{W}{C} + .000244\,\frac{W}{C}\,C = 10.08;$$

but

$$\frac{W}{C} = E,$$

therefore

$$E + 0.000244\,E\,C = 10.08,$$

and

$$E = \frac{10.08}{1 + 0.000244\,C}.$$

But

$$C = 17.25\,G,$$

and, therefore,

$$E = \frac{10.08}{1 + .00421\,G}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The agreement between the curve plotted from this equation and the experimental points is as close in this case (Fig. 161) as in those previously discussed. Other relationships may be established by aid of those already given. Perhaps the most interesting is that of draught (D) to total weight of water evaporated per hour (W), which takes the form of

$$D = \frac{.00214\,W}{10.08 - .000244\,W}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Before leaving this phase of the subject, it is of interest to

note that the plotted curves representing the derived equations (Figs. 160 and 161) are based from the equation of a straight

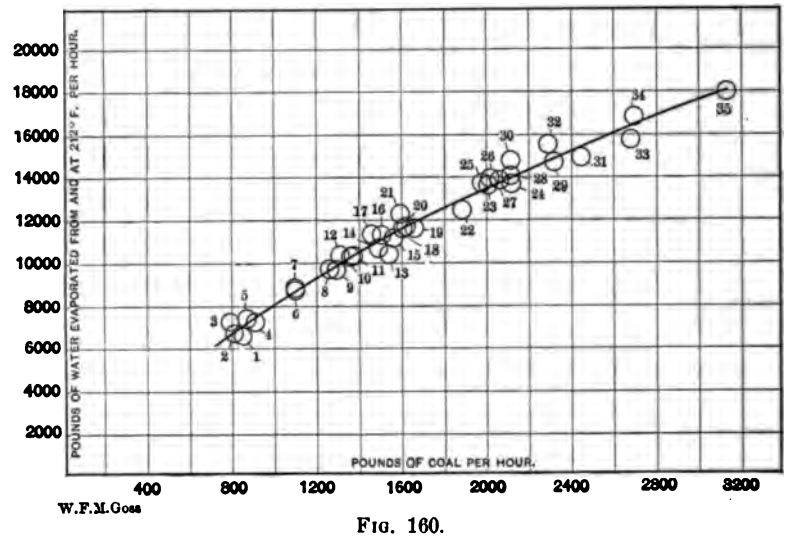

FIG. 160.

COMBUSTION AND EVAPORATION, AS SHOWN BY TOTAL POUNDS OF COAL PER HOUR AND TOTAL POUNDS OF WATER PER HOUR.

line. This straight line (Fig. 158) is believed to fairly represent the experimental points for which it stands, and it follows that

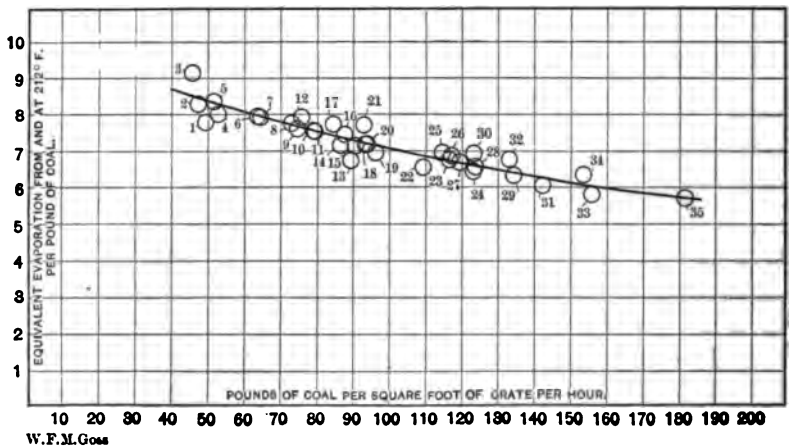

FIG. 161.

RATE OF COMBUSTION AND EFFICIENCY, AS SHOWN BY POUNDS OF COAL PER SQUARE FOOT OF GRATE PER HOUR AND POUNDS OF WATER PER POUND OF COAL.

the curves of Figs. 160 and 161 represent with an equal degree of accuracy the experimental points in the midst of which they are drawn. If, however, the experimental points represented by Fig. 161 had been accepted as a starting point for the several curves, a straight line might have been drawn through them without difficulty. Had this been done and the relation represented by Fig. 158 been mathematically derived from it, the line of Fig. 158 would have been a curve. From these considerations, and from those previously presented concerning the convergence of the several lines representing different samples of coal, it is evident that none of the relationships discussed is perfectly represented by a straight line. But with nothing but the experimental point as a basis, it appears difficult to locate a line which will better represent them than the straight line of Fig. 158, and, as before noted, within the limits for which it applies, such cannot be much in error.

III.—Conclusions.

1. The steam delivered by the boiler tested under constant conditions of running, as shown by calorimeter attached to dome, is at all times nearly dry, the entrained moisture rarely equalling 1.5 per cent., and being generally much less than this. While the relationship cannot be perfectly defined, it appears that the entrained moisture increases slightly as the rate of evaporation is increased.

2. The maximum power at which the boiler was worked with Brazil block coal was such as gave 30 boiler horse-power for each square foot of grate, and .427 horse-power for each square foot of heating surface. Experiments with other fuels indicate that these values may be increased by the use of a better coal by about 15 per cent., giving maximum values, which, in round numbers, are 35 horse-power per square foot of grate and .5 horse-power per square foot of heating surface. For the type of boiler experimented upon, and under conditions of constant running, these values may be accepted as near the maximum.

3. The maximum rate of combustion reached was 182 pounds of coal per square foot of grate per hour, which is equivalent to 2.6 pounds per square foot of heating surface.

4. The maximum draft for any test was that for which the average value was 7.5 inches. If D is the reduction of pressure

in the smoke-box measured in inches of water, and G the pounds of coal burned per square foot of grate per hour, then

$$D = .037\ G.$$

Also, if W be the total weight of water evaporated per hour, the draught necessary to produce a given evaporation is represented by the equation,

$$D = \frac{.00214\ W}{10.08 - .000244\ W}.$$

These equations apply to the boiler tested when using Indiana block coal.

5. Smoke-box temperature ranges from 550 degrees Fahr. to 800 degrees Fahr., values which are lower than those which are often assumed to prevail.

6. The evaporative efficiency of the boiler as affected by different rates of evaporation is expressed by the equation,

$$E = 10.08 - .296\ H,$$

in which E is the pounds of water evaporated from and at 212 degrees Fahr. per pound of coal, and H the pounds of water evaporated from and at 212 degrees Fahr. per square foot of heating surface per hour; this for the boiler tested using Indiana block coal, and for values of H of not less than 5 or greater than 15. With different coals the constants will vary, results which are near the minimum being expressed by

$$E_{\text{min.}} = 9.4 - .024\ H,$$

and results near the maximum by

$$E_{\text{max.}} = 12.9 - .041\ H.$$

These equations may be accepted as of rather general application, representing approximately the performance of any locomotive boiler.

7. The evaporative efficiency of the boiler as affected by different rates of combustion is expressed by the equation,

$$E = \frac{10.08}{1 + .00421\ G},$$

in which E, as before, is the pounds of water evaporated from and at 212 degrees Fahr. per pound of coal, and G the pounds

of coal burned per square foot of grate per hour; this for the boiler tested using Indiana block coal.

8. The relation of coal burned to water evaporated is expressed by the equation,

$$C = \frac{W}{10.08 - .000244\ W},$$

in which C is the total pounds of coal burned per hour, and W the total pounds of water evaporated from and at 212 degrees Fahr. per hour; this for the boiler tested using Indiana block coal.

9. The condition of running the engines, whether with long or short cut-off, or at high or low speed, does not appear to affect the efficiency of the boiler of a locomotive, except in so far as it affects the average value of the draught.

10. The efficiency of the boiler of a locomotive, as disclosed by two different tests, for which all conditions of running are the same, may vary considerably, due doubtless to inequalities in the firing.

DISCUSSION.

Mr. Frank C. Wagner.—It will be instructive to compare the results given in this very interesting paper with tests of other locomotives, and particularly with road tests. In the table below are given the principal results of two series of tests made under my direction. The tests marked *A* were road tests, made upon a 20 by 26 Baldwin consolidation freight locomotive, in 1898, a fuller account of which may be found in the *Railroad Gazette*, August 12, 1898. The tests marked *B* were shop tests of a 17 by 24 Pittsburg passenger locomotive:

Number of test.	Duration of test, minutes.	Average gauge pressure.	Pounds of coal per sq. ft. of grate.	Pounds of water from and at 212° per sq. of heating surface.	Pounds of water from and at 212° per pound of coal.	Average draft in smoke-box. Ins. water.	Average temperature in smoke-box: degrees Fahr.
1—*A*.....	256	147.6	101.4	10.1	7.26	3.7	635
2—*A*.....	243	160.8	114.5	10.5	6.70	3.3	650
3—*A*.....	245	161.1	104.8	9.78	6.82	2.9	—
4—*A*.....	241	157.1	110.3	9.91	6.55	3.8	680
Average..		156.6	107.8	10.07	6.83	3.4	655
1—*B*.....	127	151.4	23.	2.15	7.49	0.92	—
2—*B*.....	113	143.	52.3	5.45	8 27	2.8	—
3—*B*.....	135	141.1	56.4	5.53	7.82	3.23	670
4—*B*.....	37	154.	99.6	7.73	—	5.15	739

The coal used in test *A* was an Alabama coal, having 59.1 per cent. of fixed carbon, and 33.4 per cent. of volatile combustible. The total combustible—92.5 per cent.—is slightly greater than that given by Professor Goss for the Brazil block coal used in the tests he reports. The coal used in tests 1—*B* and 2—*B* contained 36.8 per cent. of fixed carbon and 37.5 per cent. of volatile combustible. The coal used in tests 3—*B* and 4—*B* contained 53.7 per cent. of fixed carbon, and 21.3 per cent. of volatile combustible.

If the average of the results obtained in tests marked *A* be plotted on Figs. 156, 157, and 158 of Professor Goss's paper, they will be found to agree fairly well with his average values. The results of test *B*, plotted on Fig. 156, give for the draught readings a line of much steeper slope than that representing the average of Professor Goss's results. The smoke-box temperatures are also somewhat higher, as would be expected.

From the above comparisons it appears that while Professor Goss's results give the general laws of the variation of the draught, smoke-box temperature, and economic evaporation as dependent upon the rates of combustion and evaporation, the exact numerical values depend upon the proportions of the particular locomotive under consideration, as well as upon the quality of fuel used.

I should like to add a word regarding the proper plan for testing the quality of the steam in a locomotive. It is a common practice to introduce the sampling nipple in the side of the steam dome, as Professor Goss has done. It has been my practice for some time to place the sampling nipple in the steam pipe, as near to the steam cylinder as possible. The difference in the quality of the steam at the two places is considerable. I have never found anything but dry or superheated steam when the sample is taken in the steam pipe close to the cylinder. It is necessary, of course, to make the pipe connection between the sampling nipple and the calorimeter as short as possible, and to cover it heavily with asbestos, so as to prevent superheating of the sample.

I do not believe that a sampling nipple placed in the steam dome gives a fair sample of the steam actually entering the throttle valve. The particles of water carried up mechanically by the steam drop back again in large part, so that the sampling nipple catches them *coming and going*, while the steam passes

steadily in one direction. Furthermore, the steam, in entering the top opening of the throttle valve, turns through an angle of 180 degrees, and leaves behind at least a part of the entrained moisture. I have tried this in a stationary boiler having a steam dome, where the priming was considerable. The percentage of moisture when the sample was taken directly from the steam dome was found to be much greater than when the sample was taken from the steam pipe.

When the throttle valve is partly closed, the pressure and temperature in the dry pipe are less than the pressure and temperature of the boiler steam by which it is surrounded, so that there is an actual transfer of heat which dries, and in some cases superheats, the steam flowing to the engine. Consequently, the heat transmitted to the steam would not be accurately determined even if the quality of the steam, as it passes the throttle, could be found with certainty.

By placing the sampling nipple in the steam pipe, close to the cylinder, the entire heat received per pound of steam, including what may be transmitted through the steam-pipe in the smoke-box, is accurately determined. And, what is more important, the exact quality of the steam as it enters the engine is also determined.

Mr. Frederick A. Scheffler.—The Society is indebted to the author of this paper, for the subject is a most interesting one, and has never before been presented to us in so complete and concise a form. The steam locomotive is frequently referred to as being extremely wasteful in fuel consumption; but all of these 35 tests show conclusively that the boiler, at any rate, is as economical as the average stationary boiler plants throughout the country, and better than a large number of them, the quality of fuel used being taken into consideration with the rate of evaporation.

The quality of the steam shown in these tests is undoubtedly much better than would actually be the case were the engine in regular running service on a track and subject to the "jarring" or "shaking up" which accompanies a locomotive, no matter how perfect the track conditions may be. I am confident that under such conditions the tendency for the particles of moisture held in suspension with the steam to combine with the latter will be greatly increased, and calorimeter readings would, therefore, show a lower quality of steam.

It might not be out of place just here to state that a form of mesh separator and superheater so successfully used and specified to-day, located in the steam space of stationary boilers (replacing the ordinary form of dry pipe), is especially applicable to locomotives, and can be readily placed in the dome in such a manner that all the steam used must pass through the separator before it can enter the throttle valve. The superheating is effected by slight wire drawing (about 1 per cent.), and temperature is raised 4 to 5 degrees thereby.

I hope to be able at the next meeting of the Society to present some tests of a locomotive in actual running condition, showing quality of steam *at the steam chest*, both before using separator and after. It is the opinion of a prominent mechanical engineer, associated with one of the largest railways in this vicinity, that superheated steam, of only a few degrees superheat, in a locomotive will greatly prevent the excessive loss of condensation in the cylinders, and also give a higher terminal pressure; and, furthermore, that passing the steam through successive layers of a mesh will prevent, to a large degree, grit from bad feed water passing into the steam chest, and thus, in time, damaging the valve seats and cylinders.

I am well aware that cylinder condensation and wear and tear of cylinders has nothing to do with the efficiency of the boiler; but the quality of the steam produced by the latter affects to a large extent the amount of cylinder condensation; hence it would seem advisable to use steam as dry and superheated as can possibly be obtained within the limits of first cost and practicability.

Mr. R. S. Hale.—There are several items of interest in Professor Goss's paper, but a careful study of them indicates that the tests were not made under the same conditions, so that they afford but little information as to what results would be obtained in similar tests. That the tests were not made under the same conditions is shown as follows:

Fig. 156 shows that for this series of tests the rate of combustion per square foot of grate is nearly proportional to the draught pressure, and is not proportional to the square root of the draught pressure, as it should be theoretically. The reasons for Professor Goss's results are probably as follows: the quantity of air passing through the interstices of the coal bed should (assuming the fire to be of the same thickness in the different

tests) be proportional to the square root of the draught pressure. In the tests at a high rate of combustion, however, there were undoubtedly a large quantity of sparks carried up the chimney that did not burn. Professor Goss's tests, elsewhere published, have shown that at high rates of combustion the amount of such sparks is 8 to 15 per cent. of the coal fired. Correcting for such sparks, and counting only coal actually burned, the rate of combustion per square foot becomes less than proportional to the draught pressure, but more than proportional to the square root of the draught pressure. As will be shown below, it is also very probable that the air-supply per pound of fuel burned was less at the high rates of combustion. If this was the case, it, together with the sparks, would account for the results shown in Fig. 156, while if the tests had all been under the same conditions as to air-supply per pound of coal actually burned, and as to the quantity of sparks per pound of coal burned, the theoretical formula, making the rate of combustion proportional to the square root of the draught, would be obtained.

I also note that equation 2 and Fig. 158, giving relations between efficiency and rate of working, correspond in form with the Rankine formula and the results obtained in my paper on "Efficiency of Boiler Heating Surface" a few years ago, and so do equations *A*, *B*, and Fig. 159. It is evident, however, even if the tests giving each of the lines of Figs. 158 and 159 were under the same conditions, that the different series as a whole are not comparable, probably on account of different air-supply per pound of fuel. That the series are not comparable is shown by the remarks in connection with Table II. If the different lines meet, they must diverge beyond the meeting point, which would give the result that the poorest coal would, at high rates of working, give the highest evaporation per pound of coal. For the poor coal to do better than the good coal could hardly be the case unless the conditions of air-supply were different, or unless there was incomplete combustion. That the conditions of air-supply were probably different is shown as follows: Rankine's formula shows that if the different series of tests are all under the same conditions, except as to quality of coal, each line would start from a point on the vertical axis nearly proportional to the calorific power of the coal when burned in a calorimeter, and would each cut

the horizontal axis at a point nearly proportional to the square of the theoretical furnace temperature, *i.e.*, to the square of the calorific value. This would make the curves of Fig. 159 converge to the left-hand side (meeting beyond the axis) and diverge to the right. Since they do just the opposite, it shows either that the assumption on which Rankine's formula is founded is incorrect, or else that the series of tests which gave the lines of Fig. 159 were under different conditions. Since Rankine's formula has on the whole been confirmed by a great many tests, and since the conditions of air-supply in the tests of Fig. 159 are not given, it is most probable that Rankine's formula is not yet overthrown, but that the series of tests were under different conditions of air-supply. This is also rendered probable by the following consideration: the constants of equation 2 depend on the air-supply. (*Transactions*, 1897, p. 340.) Now, the second constant of equation 2 (affecting H) has the value .296, which should correspond to a very small air-supply, and depends on the tests at a high rate of working. The first constant, 10.08, corresponds to a very large air-supply, and depends chiefly on the tests at a low rate of working. Therefore, if the air-supply per pound of fuel was comparatively large (probably 30 pounds or so) in the tests at a low rate of evaporation, gradually decreasing to a comparatively small amount (10 to 15 pounds) in the tests at a high rate of combustion, the results obtained in the tests would correspond exactly with Rankine's theory. That such a variation in the air-supply at different rates of combustion is very probable is also shown by the tests collected in Table XVI., page 793, *Transactions*, 1899, which show that the air-supply often decreases as rate of combustion increases. Further, such a variation in the air-supply would also explain why the draught pressure at high rates of combustion was so much less than would have been expected from the ordinary hydraulic formula. Of course, if much less air were being used per pound of coal at high rates of combustion, less draught pressure would have been necessary to force or draw this air through the interstices of the coal bed.

These deductions seem to show that the tests given in Professor Goss's paper were not made under the same conditions, but that, besides the variables of rate of evaporation, etc., which are reported, the air-supply per pound of coal also varied very considerably, being high in the light power tests and low in the

high power tests. This should be remembered in drawing any conclusions from these tests, since if the conditions had been such that the air-supply had been low in the light power tests and high in the high power tests the results might have been exactly reversed. If, instead of making thirty-five incomplete tests, Professor Goss had made half a dozen complete tests, measuring the air-supply by means of careful flue-gas analyses, he could have given us results that would have been of great value.

Mr. Rockwood.—It is said that fools will rush in where angels fear to tread. I am moved, however, to offer what I am sure will seem to the man who has made a specialty of locomotive design some foolish suggestions on that subject, which may or may not seem pertinent to Professor Goss's paper, according to how you look at it.

Professor Goss has shown that the boiler is not the worst, but probably the best, part of the locomotive. The question, therefore, which I dare to bring up is, What, if there be any, are the other elements of the locomotive which can still be improved?

Is the question really closed already? Our locomotives are now so much larger than they used to be, we generate so much more steam in a single machine than ever before, and run passenger engines so much greater distances at a time than they were run before, that the question naturally arises in the mind of an on-looker as to why the problem of radically improving the economy of the locomotive has been abandoned as one impossible of solution.

I believe that the locomotive contains a defect of elemental design which, in case of the very large machines recently constructed both in this country and in Europe, is no longer made necessary in the interest of simplicity. I refer to the use of the exhaust steam to produce a draught. This is the great cause of the wastefulness of the locomotive as compared with the stationary non-condensing power plant. It appears to me that it would not introduce much extra complication into the means for controlling the speed of the engine if mechanical draught were substituted for the present arrangement of exhaust nozzles.

The design of the Schneider fast passenger locomotive, exhibited at Paris, shows how room might be found for the necessary fans. It had, as you recollect, the engineer's cab in front

of the boiler. This seems to me to be the direction progress is taking in the development of locomotives. The Italian compound locomotive, also on exhibition at Paris, is another illustration of this tendency. This engine shows how much room there may be on the front end of the machine. I doubt not that some foreigner will soon produce a locomotive provided with fans in front of the smoke-box to create the draught. He will thus get rid of the excessive back pressure now necessary, and will heat the feed water, and perhaps the train, with the waste steam.

In this instance Americans will be too conservative even to try the experiment. Foreigners are much more active in experimenting on new features in locomotive design than we are. We are so practical that we let them lead the way, only, in most cases, to adopt, and generally improve upon, their originality later on.

I ask those who know why no one has yet availed himself of the modern high development of induced draught fans to provide air for combustion in this way? Surely this is the only great defect now to be found in the locomotive. I should think it would not be extravagrant to expect a gross saving of from one-quarter to one-third of all the coal now burned, as the result of the substitution of fans for the blast pipes. The questions to be answered are, Are the difficulties in the way insuperable? Has mechanical draught yet been given a fair test on a modern engine and according to modern ideas?

Mr. William Kent.—I think Professor Goss is to be congratulated that he has got an engine fixed up there at Purdue so that he can test it. It is an opportunity that few people in the world have ever had; and he is to be congratulated also that he has presented his results in the form he has so that they can be criticised in the manner that they have been by Mr. Hale and others, and so that he can go ahead and make further tests and give us still better results, and results having more scientific value.

I have lately been making an investigation into the causes that affect the economy of boilers, and have come to the conclusion that the air-supply is a far more important factor than it has generally been considered. In any scientific boiler test where we want to get all the data possible for the purpose of studying and comparing results, a test is not complete unless we have

sufficient analysis of the gases to judge of the air-supply. There is now made by Uehling & Steinbart a gas composimeter by which there is a continuous indication of the amount of carbonic acid in the chimney gases. There is also the Arndt Econometer. So there are two methods of getting a diagram of the amount of carbonic acid in the chimney gases from which you can determine approximately the air-supply per pound of combustible, provided the combustion is perfect. So I hope that Professor Goss will put in his plant at Purdue both the methods of testing the gases, besides a chemical laboratory, and, if possible, that he will rig up a mechanical draught to that locomotive, or a measuring anemometer, or something, so that the air-supply can be estimated at the other end.

In regard to the quality of the steam in a plant like that, where he has facilities for making tests, and time to rig up permanent arrangements, the only proper way to determine moisture is to take a separator and catch the water and weigh it. The economy of any steam boiler is a function of the temperature in the furnace and the temperature in the chimney. No boiler test is satisfactory from a scientific point of view unless we know something about the temperature in the furnace, to show whether the combustion is proper. We have the Le Chatelier pyrometer. We have the Uehling & Steinbart pyrometer, and the other day we had a description of the Bristol pyrometer. These instruments ought all three to be used in the locomotive. So that I trust that the locomotive tests will be continued with the addition to the plant of all these pieces of apparatus for testing and getting complete data. Then we will have results that we can bank on.

Mr. R. H. Soule.—We have heard one rather sharp stricture on some of the facts that have been presented in Professor Goss's paper; but I think we realize that it comes from a professional critic. I do not think that we ought to let that blind us to the fact that this is certainly a very valuable paper indeed; that it collects and presents in useful form a great deal of tabulated information which has not been available heretofore; and I think at least all that part of the mechanical fraternity which has to do with the design or performance of locomotives will substantially agree that this is one of the best and greatest contributions to the literature of that branch of the profession which has reached them in a long time. I myself think that the

information is both unique and invaluable; in fact, so invaluable that I believe we have an absolute grievance against Professor Goss in the fact that although this series of tests was completed in February, 1897, he has not given us the results until December, 1900.

I would like to request of Professor Goss that, in closing the discussion or in editing his remarks for the *Proceedings*, he should advise us on this point, whether it would be safe to generalize from the figures and curves that are given in this paper, beyond the limits of the capacity of this boiler; that is, whether it would be safe to draw inferences from these figures and curves in reference to boilers of large capacity, which are principally what we have to deal with in practice to-day. Also another thing that I think would be of great interest is the relation which exists between the rated horse-power of the boiler, as recorded on page 464, and as indicated by its evaporation of water—the relation which exists between the horse-power of a boiler determined in that way and the indicated horse-power of a locomotive. Professor Goss states at the outset of this paper that this paper gives results in so far as relates to the boiler only; but he also states that indicator diagrams were taken. Therefore, presumably, he has on record the indicated horse-power of the locomotive as revealed in the cylinders corresponding to each one of the tests here given, and corresponding to each one of the rated horse-power capacities of the boiler; and I think it would be of interest if he could put on record in the *Proceedings* two curves on the same chart, showing the relation between these two series of horse-power quantities. It would be very interesting to us to know whether these curves are parallel or whether they converge or diverge—in fact, what the relation is between them.

I am inclined to say something in answer to the gentleman on my left; not in general answer to his argument, but simply to give a single illustration in answer to his statement that he believes that we derive most of our inspiration in locomotive design and most of our improvements and good things from the other side of the water. It so happens that within the last month I received a communication from a foreign engineer, whose name I do not feel at liberty to mention, but who is conceded to be eminent as a locomotive designer. He enclosed a diagram of a new form of 4 cylinder compound locomotive, and

asked me whether I would be willing to undertake, in his interest, the introduction of locomotives of that type in America. I made a preliminary answer, simply an acknowledgment of receipt, and said I would answer in full later. I had an opportunity soon after, during a trip to Pittsburg and Altoona, to confer with my friend of 25 years' standing, the mechanical engineer of the Pennsylvania Railroad, and you can well imagine him to be a fairly good authority on such questions, and, after going over the matter, he concurred in the conclusion which I had already reached myself, that there was not the faintest chance of a 4-cylinder locomotive of that type finding acceptance anywhere in America—absolutely no chance—and that the engineer who undertook to introduce it would certainly discredit himself. I offer that simply as one instance from actual practice, and a very recent instance, to indicate the opposite of what the gentleman said, and to show that at least now and then we get some suggestions from Europe which are not acceptable to locomotive designers of this country.

Mr. C. V. Kerr.—I think I am one of the angels in this discussion, and not one of the other fellows. Referring to the question of introducing mechanical draught under locomotive boilers, I would like to recall the fact that in the early history of the locomotive mechanical draught was tried. It was tried on Ericsson's engine at that famous Rainhill contest, and I believe that it was the cause of the engine breaking down and failing during the trials. Those who will consult Pangborn's book on the World's Railways, or will examine the collection of models at Field's Museum, in Chicago, will see other engines in which mechanical draught was tried, and which have been discarded for some reason or other. It does not mean, however, that we cannot make mechanical draught succeed now. There may be some other reason. The locomotive as it stands is reduced to its simplest terms, which is necessary on account of the hard service it must endure, and it stands really as a monument to the persevering ingenuity of the men in railway service.

There is a suggestion which I would like to make, which may be discounted as much as you please, because we recognize that there are practical difficulties of construction in the way. Those who have consulted D. K. Clark's book on the steam-engine will perhaps recall experiments made on a locomotive boiler in regard to the effectiveness of different parts of the boiler in pro-

ducing steam. It was found, for instance, that the first foot of the tubes was perhaps more effective in delivering steam than all the rest of the tubes. Now, the suggestion which I would like to make grows out of this chiefly. Why not substitute in place of, perhaps, three-quarters the length of the ordinary locomotive boiler tube, the tapered tubes of the Galloway boiler and its larger combustion chamber, and simply put in three or four feet of tubes, small in diameter, as they usually are at the front end of the box? Now, this would produce a good circulation in that part of the boiler, perhaps much better than it is. It would increase the surface from which steam is liberated, and it would, I think, increase the efficiency of the boiler as a whole, due to the combustion being more perfect on account of the larger combustion chamber.

Mr. Wm. O. Webber.—Mr. President, I think the last speaker has touched upon the keynote of the greatest possible chance for improvement in locomotive boilers. This discussion, as I understand it, is on locomotive boilers, and not on locomotives. The question I have in mind particularly is the value of the different parts of the boiler in making steam, and his remarks are very true, that, in the first place, the flues are the most effective evaporative part of the boiler, and especially the front end of the flues. I think that Mr. Strong demonstrated that very thoroughly by his combustion chamber in his boiler, and there have been other boilers similarly designed; there was one designed by C. M. Higginson of the C. B. and Q. Road, which also had a combustion chamber near the fire box. It might not be uninteresting to simply mention a test that Reuben Wells, of the Louisville and Nashville Road, and myself made some years ago to see what effect the size of the fire box had on the evaporation in a boiler outside of the larger area of grate, which, of course, was a benefit. It did not seem to have any. In fact, we took a boiler and bricked up the fire box inside with fire brick all around, of course excepting the entrance to the flues, and of course we could not cover the crown sheet. But we bricked up the ends of the fire box as high as the flues and fire door, and the sides of the fire box as high as the crown sheet, and got just about the same evaporation out of the boiler as with the naked fire box. That also brings in the question which I have always thought of, and it was partly suggested by what Mr. Kent said again. I think if we could use the pyrometer as he demands, in

the fire box of the locomotive, we should find out that the water space surrounding the fire box and surrounding the fire directly above the grate keeps the temperature of combustion in the fire box down to a much lower point than would be considered good practice in any other form of boiler.

In reference to the remarks of my friend on the left, I think the most radical change that will be made in locomotives in the future will be a Parsons steam turbine locomotive, triple expansion.

Mr. Albert A. Cary.—I would like to ask Professor Goss whether he considers that the results obtained in a laboratory test, such as given here, approximate closely to a result which would be obtained under the actual running conditions of the locomotive on the road? When a locomotive is running on a roadbed more or less level, there is a constant shaking motion. We have been told by some who pretend to be authorities that this constant shaking of the boiler makes vertical sides of the fire box more efficient, on account of jarring off from these surfaces the steam bubbles, which seem to adhere to them tenaciously I do not think there is very much in this claim; but as it has been made so frequently I would like to have Professor Goss's opinion on this subject. Besides this, in the course of regular running, the locomotive is going up grade and down grade, so that the crown sheet is more or less uncovered at times, and also the rapid movement through the air would be apt to increase the condensation about the steam space and cool the water below it, thus possibly cutting down such results as would be obtained in the laboratory. It would be interesting to know whether any such comparisons have been made.

*Prof. W. F. M. Goss.**—I greatly appreciate the courteous attention which members have given to my paper. It has been urged that the value of the tests is impaired by the fact that they "were not made under the same conditions." This rather broad criticism is evidently intended to apply to furnace conditions, for it is evident that, with variations in the rate of power developed, there were of necessity variations in the rate of combustion, in the quality of the steam generated, in the smoke-box temperature, in the evaporative efficiency, and, in fact, in very many of the conditions affecting the action of the boiler. It has

* Author's closure, under the Rules.

been implied that, under all of these changes of condition, an effort should have been made to control the air-supply, that the action at the grate would have gone on without change. This, I submit, is hardly possible. Certainly such a condition does not exist in service. The tests were not designed to involve an elaborate study of furnace action under constrained conditions, but to give in simple terms a measure of boiler performance under such conditions as may be assumed to exist in actual service.

It has been suggested that the draught should vary as the square of the rate of combustion, whereas the tests show it to vary directly as the combustion. One reason for this is, doubtless, that which has been given; namely, that less air is supplied per pound of coal handled when the rate of combustion is high than when it is low. I would, however, supplement this explanation by directing attention to the fact that the draught as obtained does not represent the difference of pressure for points immediately above and below the fire. It is the difference between the pressure of the smoke-box and the atmosphere. The fire constitutes only a portion of the resistance which is offered to the free passage of air. The ash-pan and the tubes offer resistance which is independent of the condition of the fire. These influences together appear to so modify the relation of draught to rate of combustion that observations made in the manner described give results which, as shown by the paper, make the draught practically proportional to the rate of combustion.

Doubt has been expressed, both in the public discussion and by members in conversation, concerning the reliability of the results representing the quality of the steam in the boiler. It has been suggested that the steam pipe presents a more favorable point for the calorimeter than the dome of the boiler. In defence of the values given, I should say that the general subject is one which has been very carefully investigated at Purdue. Hundreds of calorimeter determinations have been made. The quality of the steam throughout its course from the dome to the cylinders has received due attention, and several publications have been made in which data have been presented. In defence of the results given in the present paper, I can only say that they are consistent with facts previously determined. The calorimeter was attached to the dome in the present tests because experience has shown it to be altogether the most satis-

factory practice, and because the Society's Committee, appointed to recommend a Standard Method of Conducting Locomotive Tests, recommend that it be so located (*Proceedings* of the Society, vol. xiv., p. 1322).

In 1893, the results of 20 tests of the locomotive at Purdue were presented to the Society (vol. xiv., p. 826). For these tests the quality of the steam in the boiler was determined by observations obtained from a calorimeter attached to one of the branch pipes, at a point half way between the T-head and the saddle, and by assuming adiabatic expansion between the dome and the point of observation, as has been suggested in this discussion. Values for moisture thus obtained range from 0.72 to 1.25, most of the tests being at light power. It was afterwards discovered that the steam in passing the branch pipes absorbs some heat from the smoke-box, and that the sample thus supplied the calorimeter was dryer than it would have been had the expansion been adiabatic by about 0.25 per cent. The corrected determination, therefore, ranges from 0.97 to 1.50 per cent. of moisture. This is in close agreement with the results now reported as having been obtained from the dome direct. Again, the results of a rather elaborate study of the transfer of heat within the front end, as presented in an article entitled, "Steam Pipes within Locomotive Smoke-boxes as a Means of Superheating," was published in the *Railway Review* for July 28, 1894. The results of the investigation thus reported show that the temperature of superheated steam was increased nearly 9 degrees in passing through the pipes in the smoke-box, also that heat is lost rapidly after the steam enters the passages of the saddle in its closer approach to the cylinder. These results should be sufficient to show that the quality of the steam in the pipe after the latter enters the smoke-box is not constant, and that the quality of the sample drawn therefrom will depend upon the location of the point from which it is drawn. It is for this reason that the dome appears to be the most satisfactory location for the calorimeter.

The question as to whether the conditions of the laboratory are comparable with those of the road has been many times asked and answered. For all practicable purposes they are comparable. Every detail of the locomotive on a testing plant, except the truck wheels, is made to work just as it would if it were on the track. The vibration of the machine as a whole, while

less severe than on the road, is nevertheless considerable. The angular forces transmitted by the connecting rods cause the engine to rock, and the roll of the wheels gives a tremor to the whole machine. The radiation of heat from a locomotive on the testing plant is, however, less than upon the road. The radiation from an engine running at 50 miles an hour has been shown to be about double that of an engine at rest (see "Test of Boiler Coverings," *Proceedings of the Western Railway Club*, 1898–99, p. 168). But the advantage enjoyed by a locomotive in a testing plant on this account is slight, the entire radiation loss for an engine on the road at a speed of 28 miles an hour being but about 2 per cent. of the heat handled by the boiler.

It has been asked, also, to what extent the general conclusions of the tests are applicable to locomotives in general. In reply I should say that values presented in the paper may be used as a basis from which to predict the performance of other locomotive boilers, provided the comparisons are made to involve the same extent of heating surface. For example, the results show (tests 6 and 7) that when the boiler is operated under conditions which permit it to evaporate 7 pounds of water *per square foot of heating surface* an hour, that 8 pounds of water are evaporated per pound of coal. It is probable that any locomotive of ordinary dimensions will, when worked at a rate of power which will result in the evaporation of 7 pounds of water per square foot of heating surface, give a similar evaporation per pound of coal; the quality of the coal being the same in both cases. In a similar manner, the maximum power which can be delivered by any boiler, or the quality of steam, or the smoke-box temperature of any boiler may be predicted from the data given, provided it is understood that values in both cases represent conditions for which the same amount of water is evaporated per square foot of heating surface per hour.

I should doubtless have avoided a portion of the criticism that has been offered by giving greater emphasis to the fact that the results presented were obtained in the course of a study of various problems affecting locomotive performance. The effort has been centred in questions such as the effect upon locomotive performance of changes in speed, or of cut-off, or of valve setting. The boiler work, therefore, has constituted one factor only in the general problem, and oftentimes a factor of secondary importance. Notwithstanding this fact, I have believed that

the results obtained from the boiler as here given, arranged in order to form a single series, present many facts of interest to the student of locomotive design. If the data are less complete than could be desired, it should be remembered that reliable information concerning the performance of locomotive boilers under conditions of service is not abundant, and that rather wild guessing is not infrequently indulged in concerning even the very elementary relationships which the paper seeks to define.

It is but just to add that none of the tests described was undertaken wholly for the purpose of securing scientific data. Their purpose was to supply an opportunity for the instruction of students in locomotive testing. It would be well if the locomotive were loaded down with all the different instruments which have been referred to as desirable; but the instruments are not there, the money is not available to buy them. It takes time, also, even after instruments are secured, to get them into successful use. I may say, in way of illustration, that we have had for several years a Le Chatelier pyrometer. It was on the engine when the tests here reported were made. It is now giving good results, and we are satisfied with it; but I want to say that if anyone thinks the mere possession of such a piece of apparatus insures an end to all his trouble, he is greatly mistaken. Solid weeks of time have been required to set up and to calibrate this pyrometer, and when established in the front end of a locomotive, its maintenance still requires frequent attention. A few more pieces of apparatus of this sort attached to a locomotive, valuable as this one has proved to be, would absorb the entire energy of a good-sized laboratory. Again, it should be remembered that a college laboratory is held up to strict performance of its routine work. Research is or ought to be dear to the hearts of all the members of its staff, but research is not first. Attention must first be given to students, the most of whom demand instruction and practice in elementary operations. The procedure at Purdue is such that when, in the round of their problems, the students come to the locomotive laboratory, the locomotive has to run. It is not allowed to wait for the last piece of apparatus which may still be in its box. I do not mention these matters to excuse imperfections which members may see in my work, or to shield myself from just criticism; but that members may understand how it is that a laboratory may possess many expensive things, even a locomotive, and may still be unable to

bring a comparatively inexpensive piece of apparatus into action at any particular time. The best for which the laboratory man can hope is to see progress in his work, to be able each year to improve his practice a little, and extend the scope of his work enough to stimulate the interest of his associates. I am glad to say for Purdue, that while we are not up to the high standard which Mr. Kent has set for us, and to which I hope we may attain, we are now doing better work with our locomotive testing plant than we were when the tests here reported were run. With reference to the courteous expression of regret that three years should have been allowed to elapse between the tests and the publication of results, I may say that the explanations already made will suggest the only defence which I am able to present.

PAPERS

OF THE

MILWAUKEE MEETING

(XLIIId)

MAY 28th TO MAY 31st, 1901.

No. 886.

PROCEEDINGS

OF THE

MILWAUKEE MEETING

(XLIIId)

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

May 28th to 31st, 1901.

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M. A. BECK,	J. F. MAX PATITZ,
GEO. P. DRAVO,	EDGAR PIERCY,
E. P. WORDEN,	EDWIN REYNOLDS,
EDW. T. ADAMS,	JNO. A. BECHTEL,
W. G. STARKWEATHER, *Secretary*,	HOWARD C. SLATER,
CHAS. P. BOSSERT,	HARRY E. SMITH,
W. P. CAINE,	JAMES TRIBE,
WM. E. DODDS,	J. S. UNGER,
JNO. C. FINNEY,	HENRY WEICKEL.

PURSUANT to a policy which has been before the Council of this Society in its deliberations as to the choice of a convention city, such choice fell upon the city of Milwaukee, Wisconsin, for the Spring Meeting of 1901. It has always been regarded as desirable when possible, that the meeting of the spring of each year should fall west of the Allegheny Mountains, so long as under the

provisions of the Constitution the annual meeting in December is fixed for the city of New York. The members resident in Milwaukee and its business interests made common cause in urging upon the Council the selection of their city, and pursuant to this pressure the arrangement was completed.

The hotel headquarters and the auditorium for the reading of papers were located in the Plankinton House, Grand Avenue and West Water Street. The headquarters was particularly comfortable and convenient, by reason of its size and its location on the parlor floor. The auditorium was in a species of rotunda in a wing, splendidly lighted and airy. The opening session was set for the evening of Tuesday, May 28th, and at half-past eight the meeting was called to order by Prof. Warren S. Johnson, chairman of the Local Committee of Arrangements, who in a few sentences welcomed the Society to Milwaukee, and turned the business of the meeting over to President S. T. Wellman, who occupied the chair during all the sessions.

The President, in brief reply, expressed the pleasure of the Society and their anticipations for a successful and profitable meeting. Professional papers were then taken up. The two papers for this session were by Messrs. W. S. Aldrich and John Riddell, entitled, "Requirements of Electricity in Manufacturing Work," and "Portable *versus* Stationary Machine Tools." In the discussion which followed, and which covered the contentions advanced by both papers, Messrs. Henshaw, Benjamin, Riggs, Jackson, Widdicombe, Comly, Knox, F. G. Bolles, Low, Reist, Johnson, and Wellman took part.

After announcements by the Secretary a recess was taken, and the members and their ladies became the guests of the Local Committee and their ladies for an informal social reunion in the hotel dining-room and parlors. The entertainment for the gentlemen took the form of a smoker. It was a noticeable peculiarity of the meeting, which manifested itself at this time, that a large proportion of those in attendance were graduates of one or another of various institutions devoted to technical education.

Second Session. Wednesday Morning, May 29th.

President Wellman called the second session to order for the transaction of business at ten o'clock, in the assembly hall.

The registration in Society headquarters, which has worked

so satisfactorily in the previous meetings, was again carried out, whereby each line of the official signature book was numbered, and each convention badge bore the same number as the member's signature.

Reprints from the register were issued every day during the session, so that the members were kept posted as rapidly as possible concerning the arrivals and registrations at headquarters. The following members were in attendance, but the list does not include a large number of residents of the city, who, by invitation of the local committee, were made the guests of the Society for its convention during the stay in Milwaukee. A gratifying delegation of ladies was also present.

Abbott, W. L.
Adams, Edw. T.
Aldrich, Wm. S.
Bacon, Jno. L.
Baldwin, Stephen W.
Barnes, W. F.
Bechtel, Jno. A.
Beck, M. A.
Belsley, Clay.
Bissell, G. W.
Bogardus, W. B.
Bole, Wm. A.
Bossert, Chas. P.
Bowen, H. S.
Bowman, F. M.
Breckenridge, L. P.
Brill, Geo. M.
Brooks, Morgan.
Bryan, Wm. H.
Bull, Storm.
Caine, W. P.
Capen, Thos. W.
Carpenter, A. H.
Chamberlain, P. M.
Colahan, Chas.
Cole, J. Wendell.
Colvin, F. H.
Comly, Geo. N.
Conway, Geo. M.
Cullingworth, G. R.
Davis, Chas. E.
DePuy, C. E.
Dingee, W. W.
Dodds, Wm. E.
Dravo, Geo. P.
Edwards, V. E.
Fellows, E. R.
Finney, Jno. C.
Fitch, J. W.
Fordyce, J. R.
Foster, E. H.
Freeman, S. E.
Gabriel, Wm. A.
George, J. R.
Golden, M. J.
Goss, W. F. M.
Hagar, Edw. M.
Hand, S. Ashton.
Heald, Geo. W.
Henning, G. C.
Henshaw, F. V.
Hirshheimer, H. J.
Hobart, F. G.
Hobert, S. G.
Horstman, H. J.
Houghton, C. E.
Hugo, T. W.
Hunt, C. W.
Hunt, Robt. W.
Hunt, W. F.
Hutton, F. R.
Jackson, D. C.
Jacobs, W. S.
Jacobus, D. S.
Johnson, C. A.
Johnson, J. B.
Johnson, Warren S.
Jones, C. R.
Keller, E. E.
Kempsmith, Frank.
Kerr, C. V.
Kimber, Geo. A.
King, Chas. G. Y.
Knox, S. L. G.
Ladd, Geo. T.
Lane, Harry M.
Lane, Francis W.
Lange, Philip A.
Larkin, F. A.
Lewis, D. J., Jr.
Longwell, H. E.
Love, Wm. S.
Low, F. R.
Lyman, James.
McClelland, E. S.
McFarland, W. M.
Mack, Jno. G. D.
Maddocks, W. H.
Malvern, L. K.
Mansfield, A. K.
Melcher, Chas. W.
Meyer, Henry C., Jr.
Miller, Fred J.
Miller, R. S.
Monroe, W. S.
Montgomery, H. M.
Moore, E. L.
Morgan, Paul B.
Neff, Elmer H.
Nistle, G. W.
Nordberg, B. V.
Otis, Spencer.
Parks, E. H.
Patitz, G. J.
Patitz, J. F. Max.

Paul, J. W.	Root, O. J.	Thompson, E. P.
Piercy, Edgar.	Royse, Daniel.	Torrance, Kenneth.
Pilton, Wm.	Salmon, F. W.	Tribe, James.
Pitkin, J. H.	Sawyer, Harry.	Unger, J. S.
Pitkin, S. H.	Scheffler, Fred A.	Van Zandt, Paul C.
Plantinga, P.	Sederholm, E. T.	Weickel, Henry.
Prosser, Jos. G.	Slater, Howard C.	Weil, Chas. L.
Reed, Wm. E.	Smith, Harry E.	Wellman, Saml. T.
Reist, H. G.	Smith, Howard W.	Wheeler, Seth
Reynolds, Edwin.	Smith, Sidney L.	Whittemore, D. J.
Reynolds, Irving H.	Sorge, A., Jr.	Widdicombe, R. A.
Rice, Arthur L.	Stanwood, J. B.	Wiley, Wm. H.
Riddell, Jno.	Starkweather, W. G.	Williston, A. L.
Richter, A. W.	Stevens, R. C.	Winther, C. A. G.
Ritchie, Wm.	Swasey, Ambrose.	Wood, E. E.
Rites, F. M.	Sweet, Jno. E.	Worden, E. P.
Robertson, C. H.	Sweeney, Jno. M.	York, Robt.

The first order of business for the convention was the reading of the report of the Tellers appointed by the Council to report upon the election of members. This report was presented by the Secretary, as follows :

REPORT OF TELLERS OF ELECTION.

The undersigned were appointed a Committee of the Council to act as tellers, under Article 14 of the Rules, to scrutinize and count the ballots cast for and against the candidates proposed for membership in their several grades in the American Society of Mechanical Engineers, and seeking election before the XLIIId meeting, Milwaukee, Wis., 1901.

They have met upon the designated day in the house of the Society, and have proceeded to the discharge of their duty. They would certify, for formal insertion in the records of the Society, to the election of the following persons, whose names appear on the appended list, in their several grades.

There were 521 votes cast on the yellow ballot, closing May 22, 1901, of which 10 were thrown out because of informalities. The tellers have considered a ballot as informal which was not indorsed with an autographic signature, or where the indorsement was made by a facsimile or other stamp.

JESSE M. SMITH,
ARTHUR M. WAIT,
STEVENSON TAYLOR,
D. S. JACOBUS,
} *Tellers of Election.*

As Members.

Alexander, L. A.
Arnold, W. S.
Ashton, A. C.
Bement, Alburto.
Benson, Orville.
Bland, J. P.
Boller, A. P., Jr.
Brown, Carleton E.
Bury, Edmund.
Coghlan, John P.
Coryell, E. M.
Darby, John H.
Duerner, H. L., Jr.
Fairfield, H. P.
Fuller, Allen J.
Gaines, F. F.
Gibbs, E. U.
Hagman, Wm. J.
Hamner, Chas. S.
Haywood, D. H.
Humphrey, G. S.
Impett, J. J.
Johnson, Carl A.
Johnston, Archibald.
Jones, John W. S.
Keilholtz, P. O.
Kent, H. R.
Kent, Robt. S.
Leach, George.
Longwell, H. E.
Loud, Henry S.
Lyman, D. E.
McCarty, R. J.
McIntosh, J. E.
McLaughlin, Jas.
McKissick, A. F.
Marx, G. H.
Messer, E. H.
Miggett, Wm. L.
Mitchell, Wm. C.
Mole, Harvey E.
Morse, E. F.
Nistle, Geo. W.
Prescott, F. M.
Raymond, Ward.
Reeve, S. A.
Reilly, Wm. J.
Riddell, A. H.
Rusbatch, A.
Rust, E. G.
Sargent, Fredk.
Savery, T. H.
Scrivenor, Arthur.
Sturgess, John.
Tufts, Leonard.
Vickess, Samuel.
Wallis, Jas. T.
Waters, Geo. H.
Weick, Chas. Wm.
Wetmore, Chas. P.
Wheeler, C. H.
Wildin, Geo. W.
Wood, Augustus.

Promotion to Full Membership.

Atwater, C. G.
Bauer, Chas. L.
Blankenship, R. M.
Bossert, C. P.
Colles, Geo. W.
Collins, B. R. T.
Curtis, Ralph E.
Ely, Sumner B.
Ely, Wm. G., Jr.
Jones, Clement R.
Knox, S. L. G.
Parker, A. W.
Rearick, C. B.
Richards, Chas. Russ.
Schnuck, E. F.

Promotion to Associates.

Gibson, James Edwin.
Ladd, George T.

As Associates.

Dyer, Frank L.
Lea, A. C.
Martinto, P.
Mason, F. H.
Morrow, P. C.
Morse, Wm. H.
Parker, J. H.
Robbins, P. A.
Sharpe, H. D.
Warren, Walter B.

As Juniors.

Ball, Fredk. O.
Bouton, Geo. I.
Childs, Geo. W.
Coburn, Richard.
Cox, Sterling B.
Crabb, Chas. L.
Davis, Herbert R.
Derbold, Charles R.
Fitz, Ervin M.
Fox, Royal E.
George, Jas. Z.
Gillet, L. A.
Grimshaw, F. G.
Guckel, Chas. H.
Hackstaff, J. D.
Harrison, S. H.
Hawkins, E. M.
Julstedt, C. J.
Keely, R. R.
Kimber, Geo. A.
Krebs, August S.
Kruesi, A. H.
Leighton, Robt. E.
Libbey, Jos. H.
Lillie, G. W.
Loetscher, Emil C.
Lovejoy, Frank W.
MacGregor, W. F.
Marshall, Wm. C.
Mason, Wm. H.
Maysilles, J. H.
Moody, H. A.
Morrison, H. S.

Naughten, James.
Newell, H. E.
Nixon, Jas. O.
Ode, Randolph T.
Osbourn, M. P.
Owstan, Chas. W., Jr.
Rand, Jasper R.
Richardson, Geo. P.
Roper, D'Arcy W.
Rose, Wm. H.
Sayers, Wm. W.
St. Clair, Jas. T.
Stroud, Edwin G.
Terrell, Cary D.
Thomson, John S.
Upson, M. M.
Van Tine, Harry A.
Weinberg, S. G.
Wehner, Lewis.
Williams, Chas. H.
Yalden, Jas. E. G.
York, Robert.
Young, George H.

The Secretary thereupon made a report announcing to the members the appointment of Mr. Arthur L. Rice, Junior Member of the Society, as an assistant in the Secretary's office. It was the purpose of the Council, in making this appointment, to increase the efficiency of the Society to its membership in general, and particularly to relieve the Secretary of the Society from attention to routine so that his services could be made more available in other and broader directions, which it had seemed to them it would be of benefit to the Society to follow.

Mr. Rice is a graduate of Worcester Polytechnic Institute, and after a postgraduate course at Cornell University he had devoted himself to teaching at Pratt Institute. He was to begin his service to the Society at this meeting in advance of the closure of his relations to Pratt Institute, and the Secretary requested for his new representative the same courteous consideration and affection which had been extended to himself.

The Secretary then read the following report of the reunions which had been held in the city of New York during the past winter, under the auspices of the Committee of Junior Members.

The Committee on Junior Meetings respectfully presents to the Council of the American Society of Mechanical Engineers the following report of the work which has been done during the past winter:

Five meetings have been held, and papers presented.

November—John C. Wait on "The Laws of Construction Contracts." Attendance, about seventy-five. Ten requests for papers were received from New Jersey, Connecticut, Nova Scotia, Massachusetts, Ontario, Illinois, New York, Colorado, and Wisconsin.

January—Cornelius Vanderbilt on "Locomotive Fire Boxes." Attendance, room overcrowded. Two requests for papers were received from Ontario and Michigan.

February—John C. Wait, "Laws of Construction Contracts"

(second paper). Attendance, about fifty (night very rainy). The requests for papers were about the same as for the first paper.

March—F. O. Ball on "Drafting Room and Shop Records." Attendance, about eighty. Two requests for papers from Colorado and Ohio were received.

April—Ernest H. Foster on "Superheated Steam." Attendance, about sixty-five. Three requests for papers from Pennsylvania and New York.

Of these papers the Publication Committee of the Society will print those by Messrs. Vanderbilt, Ball, and Foster in the *Transactions*. Messrs. Vanderbilt and Ball were Juniors. As Mr. Wait is not a member of the Society his papers were ineligible for a place in the *Transactions*.

The statement of the expense of conducting the meetings for the past winter is as follows, the detailed account being appended:

Printing	$30 00
Postage	32 79
Lighting and current	10 75
Other expenses at meetings	6 50
Telegrams, etc.	5 00
	$85 04
Stenographer's reports of meetings	128 50
Total	$213 54

With regard to holding similar monthly meetings in the future, it is the opinion of this committee that it can only be done successfully by a differently constituted body. Where each member of the committee is liable at any time to business calls demanding his first attention, the result must be an early demoralization of the committee and of its work.

Strictly Junior Meetings are neither approved by the body of the Juniors nor by the present committee, as is shown by the report of the meeting of May 2, 1900, on file in the Society's library.

In view therefore of the difficulties in the way of conducting successful meetings under the present scheme, difficulties which are inherent, and which must sooner or later result in failure, and believing that such failure would be harmful to the best interests of the Society, our committee unanimously voted to tender its resignation.

Respectfully,

(Signed) FRANCIS E. FROTHINGHAM, *Secretary.*

The Secretary stated at the conclusion of the reading of this report that the resignation of the committee had been accepted, and that the Executive Committee of the Council had it under consideration to report a plan for continuing reunions in the Society house in New York City under the auspices of the Secretary's office instead of through a committee of Junior Members. Due announcement of the decision of the committee would be made to the members by circular letter when the committee had acted.

Under new business, Mr. H. G. Reist of Schenectady presented, on behalf of his associates, the following communication. He submitted it with earnest urging that the matter of a meeting of the Society at Saratoga in the near future should be favorably considered.

TO THE COUNCIL OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS:

We, the undersigned members of the Society living in the vicinity of Saratoga, Schenectady, Troy, and Albany, do hereby petition the Council to select Saratoga for the place of the spring meeting for 1902.

We would respectfully call attention to the following reasons which, to our minds, make this point an ideal one for the purpose:

First—Saratoga is very centrally located with reference to the New England and the Middle States, having accommodations by several lines of railroads from the West, South, East, and by one from the North.

Second—Saratoga has large hotel accommodations, which at this season of the year are unoccupied. It may be necessary to hold the meeting the first or second week in June, as before this time the hotels will not be open.

Third—The large and varied manufacturing interests in the locality which may be inspected by members. Among these are the lumber, pulp, and paper mills on the Hudson, the power transmission plants at Spier's Falls and Mechanicsville, the locomotive works and general electric works at Schenectady, the various iron works and collar and cuff industries at Troy, and the United States Arsenal at Watervliet with the Army gun factory.

Fourth—It is a convenient centre for making pleasure excursions to points of historical and scenic interest, among which may be mentioned Lakes George and Saratoga, the Hudson River at

various points, and the mineral springs at Saratoga, which are always of interest.

Fifth—No meeting of the Society has ever been held in this section.

Sixth—The master mechanics and master car-builders have found Saratoga so convenient that they have made it the permanent meeting place for their organizations.

Signed:

JOHN RIDDELL,
A. L. ROHRER,
H. G. REIST,
J. E. SAGUE,
L. R. POMEROY,
F. J. COLE,
CHARLES H. APPS,
E. M. HEWETT,
FREDERICK MACKINTOSH,
S. L. GRISWOLD KNOX,
C. M. SPALDING,
W. B. POTTER,
W. A. PEARSON,
WILLIAM G. ELY, Jr.,
J. M. B. SCHEELE,
JOHN R. SLACK,
FREDERICK B. COREY,
CASPER MORTENSEN,
A. J. PURSIN,
OLIN H. LANDRETH,
SETH WHEELER,
FRANK G. BROWN, Jr.,
JAMES A. BURDEN,
JAMES H. BLESSING,
GILES BEACH,
ALFRED CHRISTIANSEN,
ALBERT E. CLUETT,
J. F. W. HARRIS,
JAMES F. MCELROY,
PALMER C. RICKETTS.

The President in reply said that the matter would receive careful consideration at the hands of the Council, which was not ready to announce any decision at so early a stage.

Professional papers were then taken up.

The Reports of Committees were deferred until a following session, at which the reporter of each committee hoped to be present with the completed document. The papers were as follows: "The Practical Application of Superheated Steam," by Geo. A. Hutchinson; "Superheated Steam," by E. H. Foster; "Drafting Room and Shop Systems," by F. O. Ball; "Blue-printing by Electric Light," by H. G. Reist; "Rules for Drawing Office," by A. W. Robinson; and the participants in discussion were Messrs. Foster, Goss, Bull, King, Comly, Bole, Weil, Henshaw, Christie, Knox, Bancroft, Griffin, Smith, Neff, Blood, Capen, Hunt, Wellman, and Sawyer.

After announcements concerning the excursions a recess was taken.

The afternoon of this day was devoted to excursions to the manufacturing interests of Milwaukee. The party was divided

along the lines of its individual preferences, so as to provide for visits to the E. P. Allis Company's works, the Filer & Stowell Manufacturing Company, the Nordberg Manufacturing Company, and the Christensen Engineering Company.

Special cars of the electric system of Milwaukee were chartered and put at the service of the visitors, who made use of them under a well-ordered time table. During the morning and afternoon of this day the Ladies' Committee entertained their guests by a drive and a visit to the Public Museum and Library Building. In the evening the members and their ladies were the guests of the Local Committee at a reception and conversazione at the Deutscher Club on Grand Avenue. The officers of the Society and the chairman of the Local Committee received the guests on their entry into the large reception-room, and later in the evening a banquet was served in the dining-hall of the club. The club stands in attractive grounds, which were illuminated during the evening.

Third Session. Thursday Morning, May 30th.

The first business was the presentation of the preliminary report of the Society's committee appointed to codify and standardize the methods of making engine tests. It was the purpose of the Committee to present this paper for discussion on its technical side to the membership, so as to elicit their comments and criticisms. On the basis of such criticism the final report would be made at the annual meeting, and the usual action of the Society would be requested. Messrs. Christie, Hall, Hibbard, Thurston, Sederholm, and Hugo took part in the discussion, and Mr. C. W. Hunt presented the following resolution, which was duly seconded and adopted:

Resolved, That the Council be requested to consider, and if they consider advisable, to print suitable blanks arranged for convenient practical use in testing and filing, for a permanent record, of the "complete form" and the "short form" of making engine tests, recommended by the Committee. These blanks to be furnished to members at a price covering their cost.

The text of the report appears as an appendix to this pamphlet of Proceedings, and is numbered 887.

The papers of the morning were then presented in their order: "Influence of Titanium on the Properties of Cast Iron and Steel," by A. J. Rossi; "A Few Instruments of Precision at the Paris

Exposition of 1900," by Wm. E. Reed; "Bevel-Gear Cutting Machines at Paris," by Fred J. Miller; "The Locomotive Exhibits at the Paris Exposition of 1900," by Storm Bull; "New Connecting-Rod End," by C. W. Hunt; and "Method of Filing and Indexing Engineering Literature, Notes, Data, etc., etc.," by Geo. H. Marr; the discussion being offered by Messrs. Swasey, Goss, Reed, Freeman, Christie, Smith, and Breckenridge.

In connection with his paper, Mr. Rossi presented an exhibit of illustrative specimens.

In the afternoon the Society were again the guests of its Local Committee for a ride by trolley cars to the attractive surroundings of Waukesha. Carriages were awaiting the party at the terminus of the road, and after a visit to two or three of the springs, for which the locality is famous, and a drive through its principal streets, the party returned to the cars and were conveyed home.

In the evening a reunion of the members and guests was held in the dining hall of the hotel.

Fourth Session. Friday Morning, May 31st.

The following papers were taken up: "A Filtration Plant at Albany, New York," and "Tests of an Hydraulic Air Compressor," by Wm. O. Webber; "The Bardwell Votometer," by Messrs. A. F. Bardwell and James Hamilton; "Some Experiments on Ball Step-Bearings," by C. H. Benjamin; "Determination of Fly-wheels to Keep the Angular Variation of an Engine within a Fixed Limit," by J. I. Astrom; and "A Special Form of Boring and Facing Machine," by W. S. Russel. The participants in debate were Messrs. Adams, Thurston, Hugo, Henning, Bull, Sweet, Gray, Hunt, Abbott, Chamberlain, Kerr, Jackson, Reist, and Mansfield.

During this session the ladies were again the guests of the hostesses of Milwaukee for a visit to the Layton Art Gallery. Small parties were also escorted in steam automobile carriages through the attractive parts of the city and parks. In the afternoon carriages provided by the Local Committee conveyed the party to the Mechanical Massage Department of the Sacred Heart Sanitarium, where a most complete exhibit of the Zander ma-

chines for Swedish massage were exhibited, and much amusement was caused by certain of the younger members who participated actively in the illustration of their completeness. The hydropathic and other departments of the sanitarium were also visited and admired. Leaving here, the drive took the visitors through the Soldiers' Home Park and other attractive park districts of the city, and so back to the hotel.

Fifth Session. Friday Evening, May 31st.

In the evening, at 8:30, the Society convened for its closing session. The following papers were presented:

"Efficiency Tests of a One-Hundred-and-Twenty-five Horse-Power Gas Engine," by C. H. Robertson; "A Method of Preparing and Baling Cotton in Round Bales of Uniform Lap," by John R. Fordyce; "Protection of Ferric Structures," by M. P. Wood; and "An Improved Type of Ingot-Heating Furnace," by F. H. Daniels; and in their discussion Messrs. Scheffler, Jackson, Comly, and Wellman took part.

At the close of the professional session the President, under Article 31 of the Rules, announced the appointment, as required by the constitution, of the following persons, to serve as a committee to nominate officers for the Society for the ensuing year:

Messrs. Robt. W. Hunt, Chicago, Ill.
Walter C. Kerr, New York City.
Fred H. Daniels, Worcester, Mass.
Harris Tabor, Elizabeth, N. J.
C. H. Benjamin, Cleveland, Ohio.

The Secretary, under the requirements of Article 45 of the Rules, gave notice in writing, by direction of the Council, of a proposed amendment to Article 18. The proposed amendment was as follows:

Whereas, A resolution has been presented in the Council by one of its members, looking to the advisability of an increase in the rate of the annual dues in the Society, and whereas the Council has given favorable consideration to this proposition,

Notice is hereby given of an amendment to be taken up and considered at the annual meeting to amend Article 18 as follows:

The initiation fee of a member or associate shall be $25, and the annual dues shall be $25, payable in advance. The initiation fee of a junior shall be $15, and his annual dues $15, payable in advance. A junior being promoted to any other

grade of membership shall pay an additional initiation fee of $10. Any member or associate may become a life member in the same grade by the payment of $350 at one time, and shall not be liable thereafter to annual dues.

The Secretary, on behalf of the meeting and a committee for this purpose, presented the following series of resolutions, which were passed unanimously:

The American Society of Mechanical Engineers, at the closing session of its forty-third meeting at Milwaukee, Wis., desires to put on record its sincere thanks and recognition for the courtesies which the Society has enjoyed during its stay in Milwaukee.

There seems to be no other mode than the accepted form of resolutions, whereby a deliberative body such as this can express its intentions and desires. The committee appointed for this purpose would therefore ask that the meeting will consider and accept the following resolutions:

Resolved, That the Society records at this meeting the sense of obligation which is imposed upon it by the unremitting and wisely directed efforts of the Local Committee of Arrangements, in whose hands must necessarily fall the details of the programme of its meetings. The Society therefore requests that the Local Committee will feel assured by this action of the keen and sincere thanks of the members of the Society for the efforts of that committee and for their conspicuous success. The success is due not only to the wise planning in advance of the meeting, but the efficient organization and administration of its members during the various excursions. Administrators and executors themselves in many cases, they are most recognizant of these elements of success in those in whose hands they have been during the successful Milwaukee meeting.

Resolved, That in so far as a group of simple men may venture to make themselves the mouthpiece for the ladies who have accompanied the visitors to Milwaukee, the Society would express to the Ladies' Committee their keen appreciation of all the efforts which the Ladies' Committee has put forth, beginning with the very first day of the meeting and lasting through until its very end on Friday. The ladies would appreciate not only the provisions themselves, but the kindly and self-sacrificing way in which these entertainments have been carried out by their hostesses.

Resolved, That the thanks of the American Society of Mechanical Engineers are due and are hereby expressed to those manufacturers and other business interests of the city of Milwaukee, to whose courtesy are due the privileges which have been granted, of the enjoyable visits during the meeting. And they would express their sympathy to those who have been compelled by the exigencies of the time to take a position in which their hearts were not enlisted, and hope that a speedy solution of all difficulties may soon be reached. It is impossible by a single resolution to reach every one of their hosts in detail, but the meeting directs and requests that the Secretary of the Society will transmit copies of this resolution to firms and corporations who have placed the Society under a debt of obligation.

The convention thereupon adjourned, to be reconvened for its regular annual meeting in the city of New York during the week following Thanksgiving.

No. 887.

APPENDIX TO THE PROCEEDINGS.

REPORT OF COMMITTEE ON STANDARDIZATION OF ENGINES AND DYNAMOS.

1. The Committee on Standardization of Engines and Dynamos has nearly completed its labors, and is prepared to submit a second tentative report, which, however, it believes is in such shape that very little change will be required when the final report is made.

Since the report of a year ago at Cincinnati, the committee has held two formal meetings and conducted a very large correspondence. At the conclusion of its last meeting, in April of this year, a circular letter was sent out to the builders of engines and generators containing the recommendations of the committee upon the various features which required standardization. It is a great pleasure to be able to report to the Society that the replies which have been received are almost without exception commendatory, and express a willingness to conform to the recommendations. The exceptions were of such a nature that it was practical to meet them without change. The report which we submit below includes the changes made to meet these exceptions, so that we are justified in saying that this report meets the views and practice of practically all of the engine and generator builders of the country.

It gives us pleasure to state that the Engine Builders' Association of the United States, at a recent meeting, after examining our report, passed a resolution heartily approving the recommendations, and promising cordial coöperation in securing the carrying out of this scheme for standardization.

2. The report which we submit below covers all the features to be standardized, with the exception of proportions of keys, and shrinkage allowance for armature fits. These we expect to consider at once, and hope at the December meeting to make a final report. We now submit recommendations upon the following points which needed standardization, most of which are shown in the accompanying table:

1. The standard sizes of units recommended.
2. The corresponding revolutions per minute for these units.
3. The sizes of shafts for the two classes of centre-crank and side-crank engines.
4. The length along the shaft required for the generator.
5. The height of axis of shaft over top of sub-base.
6. The width of top of sub-base.
7. Armature fit.
8. Overload capacity of generators.
9. Brush-holders.
10. Holding-down bolts, keys, and outboard bearings.

Size of Units.

3. As stated in our tentative report of last year to the Society, we have endeavored to reduce the number of standard units to the fewest sizes. This will commend itself to all manufacturers as tending to reduce the great number of patterns required to be kept on hand. We have learned from letters received from manufacturers that the 250-kilowatts unit, which we included in our list of standard sizes, is regarded as rather large, and conforming to what we believe to be a general desire we have taken this size out of our list, leaving the 200-kilowatts unit the largest to be standardized.

Revolutions.

4. These standard speeds have been chosen after very careful deliberation and investigation of the practice of all the engine and generator builders in the country. It will be observed that we have provided for a permissible variation of speed of FIVE PER CENT. above or below the mean speed which we recommend, and an examination of the practice of all the engine and generator builders shows that this covers practically all the machines which may be considered as of standard make at the present time, and we have been assured by some builders whose conditions differed somewhat, that if there is a general agreement upon the scheme outlined they will be prepared to make their machinery to conform to the recommendations.

Shaft Diameters.

5. These are also the result of careful analysis of the existing practice of all manufacturers, and a consideration of all the condi-

tions affecting the diameter of the shaft. The preliminary report which we sent out to the manufacturers has elicited only a few adverse criticisms, and these after correspondence were withdrawn.

Length of Generator along the Shaft.

6. When we came to investigate the question of length along the shaft (between limit lines) to be provided for the generators, we found that the practice of manufacturers required provision for two classes, which may be called "long" and "short" generators.

It would, of course, have been much better if we could have provided for but a single class, with a small allowance for variation, but there is such a marked difference in the lengths for the same power that we have deemed it best to make provision for these two classes, so that the engine builders can govern themselves accordingly. It will be noticed that the maximum difference in lengths between the two classes is six inches, which in the small sizes is reduced to five inches.

In the case where an engine is to be provided for a generator which falls into the "long" class, but which is only a little over the limit for the "short" class, or one which is considerably less than the maximum of the "short" class, the excess clearance is to be provided for on the side next to the engine; that is to say, the side away from the commutator.

We have carefully considered the fact that for these varying lengths of generator and shaft the engine builder has to provide different lengths of sub-base, and in order to reduce the expense of patterns here to a minimum, our idea is that these patterns would be made so that the end away from the commutator can be extended the necessary amount, five or six inches, to take care of the increased length of bed. Obviously, this means simply a standard pattern with a standard adjustable end for each unit.

Height of Shaft.

7. As is well known, there are two classes of generators to be provided for under this head, those which are split vertically and those which are split horizontally. The former have a flat base, which rests directly upon the flat top of the sub-base, while the latter have feet which take the weight of the generator.

In order to arrange that the engine builders' patterns may be reduced to a minimum, and still may be stock patterns which will fit every style of machine, we have chosen dimensions for height of axis of shaft above top of sub-base sufficient to allow for the vertically split machines, and also to clear the periphery of the horizontally split machines.

As will be seen, the scheme provides for a main pattern, to which patterns for the stools and seatings for both horizontally and vertically split generators can be attached before the pattern is sent to the foundry—stools for the horizontally split machines and rectangular seatings for the vertically split machines.

We believe that this is one of the most important matters we have considered, and we trust that our solution of the problem will commend itself to the Society. Those engine builders with whom we have already conferred consider that the scheme is entirely feasible and involves a decided minimum of expenses.

Width of Top of Sub-base.

8. This has been decided by careful examination of existing practice, and we believe that the figures we have recommended will cover the necessities for all sizes of generators.

Armature Fit.

9. The matter of armature fit has received very careful consideration from the Committee, and our recommendation is for what is known as a single fit. We were aware that one of the largest manufacturers of electrical apparatus used two fits, and we were well acquainted with the excellent reasons which are given for this practice. Very careful consideration of the great object which we must always have in view—standardization—has shown us that this can only be attained satisfactorily by having the single fit. We have now obtained an authoritative consent by the firm using the double fit to use the single fit.

Overload Capacity of Generators.

10. All of the other features of our recommendation have had to do with the question of dimensions as affected by the mutual relations of the generator and the engine. An important question,

however, which affects both the generator and the engine is that of the overload capacity which can reasonably be expected. As is doubtless well known, generator builders are frequently called upon to provide for overloads for short periods of as much as 50 per cent., and even in occasional cases of 100 per cent.

It is very evident, however, to every engine builder that to provide an engine large enough to drive the generator under such extreme overload capacities is something beyond the reasonable capacity of the rated load of the engine and seriously interferes with the economy with which the power is produced.

Bearing in mind that our recommendations are entirely for standard practice, we are led to recommend that the standard overload rating should not in any case exceed 25 per cent. of the rated capacity.

If, under peculiar conditions, a higher overload capacity is demanded, it must be understood that this is a special case not covered by the standard machines, and provision must be made for meeting this demand accordingly.

Brush-holders.

11. We recommend, what we believe is now the practice of the best generator builders, that the brush-holder rigging shall be supported from the generator frame. This, we think, will commend itself as making the electrical part of the outfit entirely self-contained.

Holding-down Bolts, Keys, and Outboard Bearings.

12. We recommend that the holding-down bolts, shaft keys for securing the generator hub to the shaft, and the outboard bearings should be furnished by the engine builders. This is in accord with almost universal practice at the present time.

Our recommendations for these last two headings do not cover matters of so great importance as some others; but, if adopted, they will tend to settle certain points about which there occasionally has been dispute and considerable controversy and correspondence.

It is a pleasure to us, in concluding this report, to add that we have had the cordial and hearty coöperation of the manufacturers of both engines and generators. They have recognized that our

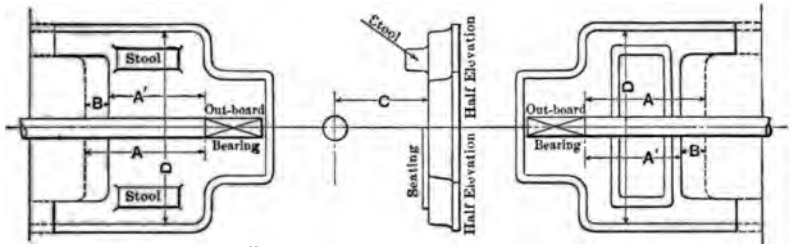
work is for their benefit, and they have shown a most commendable willingness to make reasonable concessions in order to secure the end in view.

Yours very truly,

THE COMMITTEE ON STANDARDIZATION OF ENGINES AND DYNAMOS, OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS,

By J. B. STANWOOD, *Chairman.*

PROPOSED STANDARDS FOR
DIRECT CONNECTED ENGINES AND GENERATORS.



As arranged for horizontally parted generators.

Stools to be made and located to suit feet of horizontally parted generators. Builders of latter note that radius of outside of field piece must be ¼" to ½" less than "C."

As arranged for vertically parted generators.

Rectangular seatings to be made and located to suit bases of vertically parted generators.

STANWOOD

FIG. 237.

Capacity of Unit K. W.	Revolutions per Minute.	Armature Bore.		Space occupied on Shaft between the Limit Lines.		B Length of Lengthening Pieces.	C Height of Axis of Shaft above Planed Top of Base.	D Width of Top of Sub-base.
		Centre-crank Engines.	Side-crank Engines.	Long Class A.	Short Class A'.			
		Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
25	310	4	4½	30	25	5	23	48
35	300	4	5½	33	28	5	25	54
50	290	4½	6½	37	31	6	28	60
75	275	5½	7½	43	37	6	31	66
100	260	6	8½	48	42	6	35	72
150	225	7	10	51	45	6	41	84
200	200	8	11	54	48	6	49	96

Five per cent. variation of speed permissible above and below speed in table.

NOTE.—Distance from centre of shaft to top of base of outboard bearing may be less than "C" **(to suit engine builder)**, though not less than possible outside radius of armature.

DISCUSSION.

Mr. F. V. Henshaw.—In reference to the question of overload, I would say that while the units comprised in this report are so small that they do not enter largely into electric-railway practice, yet the range is sufficiently large to cover 150 and 200 kilowatt machines used in railway service; and as the demand for overload capacity is so much greater for such service than it is in other classes of work, I do not think that it would be practicable to adopt 25 per cent. overload unless we eliminate railway service. In other words, electric generators can be divided into two distinct classes: one for lighting and general power, and one used for railway work; in the latter the requirements are very much more severe, and it is not at all unusual to specify 100 per cent. overload momentarily, and 50 or 75 per cent. for anything from half an hour to three hours.

Another suggestion which I would like to make—although I do not know that it will meet with approval—is that in small units having centre-crank shafts, coupled shafts be adopted, using a short shaft with a flange coupling for the generator end, and thereby avoiding shipping a centre-crank shaft around the country; it is very cumbersome when an armature is attached to it, and an accident is liable to spring the crank. The other method is more convenient, and a short shaft is easily put into an armature by the dynamo builder without risk of damage.

Mr. A. K. Mansfield.—I would like to suggest that it would be well to include in the report some more definite explanation as to the five per cent. clause. That is, the clause which permits the generator, or the engine and generator, to be run at five per cent. above or below the nominal speed given in the table. I do not understand how this is brought about. I do not suppose it is by any new discovery in the art of building electrical machinery. Engine builders generally are compelled to run their engines at exactly the speed demanded by the generator builder. The clause appears to enable the engine builder to fix the speed within limits. How is this great convenience brought about? Perhaps some of the generator builders here present can give us information on this subject.

Mr. H. G. Reist.—While I do not know why that clause is put into these recommendations, there is one very good reason why it is necessary. That is, in driving alternating-current

machines of different frequencies it is not always possible to make machines of a given capacity which will run at the same speed.

Mr. J. B. Stanwood.—Pardon me. This report relates only to direct machines. It does not take in alternating-current machines at all.

Mr. Reist.—I supposed that alternating machines would be included, being operated from the same engines. I might simply explain what I started out to say, which is, that for different frequencies, as, for instance, 25, 40, and 60 cycles, it is not always possible to select for machines of given capacity a number of poles to give the same speed.

Mr. Henshaw.—In reference to Mr. Mansfield's point, it is desirable to have a speed range for the reason that voltage is not standard. In one plant they will operate at 230 volts, and in another at 240 and another at 250. Now the same generator is used in any case, and the proper adjustment is to change the speed in direct proportion to the voltage.

Mr. Mansfield.—I would say in reply that the response which the gentleman just made takes away all the leeway which the report seems to give to the engine builder. I thought that we were getting together a little better than that.

Mr. Henshaw.—I think the rule works both ways. It simply gives something to come and go on. The voltage of the generator might be reduced 5 or 10 or even more per cent. without changing the speed; but it is better for the generator to reduce it in proportion to the voltage. If the reduction is, we will say, 5 per cent., the dynamo builder might give 2½ and let the engine builder have the other 2½ per cent.

Mr. William H. Bryan.—This report is of very great practical value, not only to manufacturers, but also to the consulting engineer; I would suggest, therefore, that it be printed and distributed as early as possible for immediate use. I would also suggest that if there are good reasons why the report as presented is not applicable to alternating-current machinery, that it be taken up further with a view of making it applicable and available in that direction. Practically all the smaller central stations are now using alternating current, and all want to use direct connected machinery.

Mr. W. M. McFarland.—I might explain that one reason why the report of our committee was not printed and distributed, is

because we deemed it necessary, after our last meeting in Pittsburg, to prepare a circular letter which is practically identical with the report which has been read to-day, and which we sent out to all the engine and generator builders with whom we had been in correspondence. Our object in this was that, when we made our report to the Society, we might be able to say that our recommendations had been seen by the manufacturers who would have to adopt them if they are to have any effect, and that the report met with their general approval. The time between our meeting and the meeting of the Society here was not very long, and up to our arrival in Milwaukee we had not heard from one of the most important firms involved. We did not, in fact, get a reply from them until we telegraphed yesterday asking if our recommendations met with their approval. We have since had an answer from them saying that they do approve our recommendations. Obviously, under the circumstances, it was impossible to have the report in print. I am glad to say that the replies we have received from the manufacturers are extremely encouraging, because all agree with our recommendations except, in a few cases, with respect to a few details. We were able to modify these details so as to meet the views of these manufacturers. The report as just read by Mr. Stanwood is in such shape that we can safely say that it meets the approval of all the manufacturers involved.

With respect to the question of overload limit, and the point made by Mr. Henshaw, I am afraid he overlooked one point in our report. Our recommendation was that *standard* units should be expected to give only 25 per cent. overload. If a machine is wanted to give a higher overload, as is generally the case with street railway practice, then such machines would be regarded as special. As a matter of fact, this question would hardly give any practical difficulty, for the reason that our report relates only to units of 200 kilowatts and under, while the tendency in street railway practice is to use units of much larger capacity.

This same point of size applies to the question of alternating currents. While there are, of course, a great many alternating-current units smaller than 200 kilowatts in use, the tendency in most cases, where standardization would be of importance, is towards much larger sizes. I may say, however, that our committee has dealt only with direct-current units, and that most of the concerns which have aided us with their advice and data

have stated practically that they were only considering direct-current units in the standardization. It might, of course, be desirable for our committee later on to take up this question of alternating-current units, but for the present it is undoubtedly better for us to go along on the lines we have already followed.

With respect to the point made by one speaker—that he would be glad to see a provision that the connection between centre-crank engines and the generators driven by them should be by means of a special form of coupling—I may say that this is a detail which we have not examined because the point was never brought to our attention by any of the manufacturers of either engines or generators as one requiring special standardization. We have felt that it was more important to settle those questions where there was diversity of practice than to attempt to cover all possible points where standardization might be desirable.

The most important matter for our committee was to do something to cure the difficulty now existing where different makes of engines and generators of nominally the same capacity differ greatly as to speed, shaft diameter, and other like points. We have endeavored to arrange matters so that any engine of a given capacity will match with a standard generator of the same rated capacity.

In this connection it is proper to answer the question raised by another speaker as to how the five per cent. allowance for speed variation will work. I may say, in the first place, as was explained at the Cincinnati meeting a year ago, that we approached this subject without any preconceived theories or attempts to secure absolutely ideal conditions. We went to all the engine and generator builders to find what was their existing practice. With the data thus obtained, we plotted on cross-section paper the capacities and speeds, and finally were able to trace in a curve which was a good general average. To include all the builders, however, it was necessary to allow a certain amount of speed variation, and this we were fortunately able to arrange owing to the elasticity of the generators, which will allow a variation of five per cent. above or five per cent. below the average speed. We found that some engine builders run uniformly to low speeds while others run uniformly to high speeds. We are able to say, however, that if the engines do not differ from the standard speed more than five per cent. above or five per cent. below, they

will match up with standard generators of the same capacity as the engines.

We received a letter yesterday from one manufacturer who said that he did not see how a generator builder could be expected to furnish a low-speed machine for the same price as a high-speed machine. We consider this a matter entirely beyond the purview of the committee, because we are discussing only the engineering features of the case and not the commercial aspects. Questions of price are something to be settled by the individual builders.

What we have attempted to do, and what we believe we have succeeded in doing, is to provide such a state of standard conditions as will enable any engine of a given capacity to match with a generator of the same capacity, provided the features which we have included in our report are complied with.

No. 888.*

A NEW CONNECTING-ROD END.†

BY C. W. HUNT, NEW YORK CITY.
(Member of the Society.)

THE adjustable bearings in a connecting rod are the most troublesome to fit up of any used in steam machinery. The stresses alternate so rapidly, that any looseness in the parts of the bearings is followed by such violent shocks to the mechanism that the most rigid construction is required to prevent serious injury.

The method of construction, necessarily used from the peculiarities of the ordinary designs, requires the work to be done on slotting, shaping, or other machines that must be manipulated by a skilful workman. These machines are not fitted to do rapid or duplicate work, nor is it convenient or even possible in many cases to obtain workmen having the requisite skill to make a bearing with the accuracy that the maker sets up for his standard.

In an effort to make a design which will require less minute measurements and highly trained personal skill, I have arranged the method of taking up the wear, in a connecting rod or other bearing, which is illustrated in the cuts herewith shown. The work is done on machines which with ordinary attendance lend themselves admirably to duplicate work and accurate results.

The sides of the rod are planed off, and the ends turned or milled to bring the exterior to the finished shape shown in Fig. 162, or bolted rigidly together, as in Fig. 165.

A hole for the wedge *B* is then drilled and reamed at an inclination with the axis of the crank pin of about one in ten. In

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* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† For other references on this subject consult:

No. 125, vol. iv., p. 368: "Balanced Vertical Engines." W. F. Durfee.

No. 588, vol. xxi., p. 751: "A New Mechanical Fluid." C. W. Hunt.

No. 295, vol. ix., p. 466: "Connecting Rods." W. F. Mattes.

No. 733, vol. xviii., p. 737: "Current Practice in Engine Proportions." John H. Barr.

this hole the cylindrical plug B is inserted. It is made an easy sliding fit, but is temporarily held fast during the following manipulations by a wedge key, or other means, while the hole for the crank-pin bushing G is bored at right angles to the axis of the rod. Both holes are cylindrical, but their angle to each other makes B a wedge, convex on the rod side and concave on the bearing side. The holding key is now removed, and B is free to move any distance in the direction of its axis, but if it is moved endwise it will throw the concave side towards or from the crank pin A. To adjust and hold B in position a screw C is fitted with two collars to embrace the ends of the wedge. This screw may be fitted wrench tight to hold it securely in any position, or it may be held by other means in large bearings.

To illustrate the delicacy of adjustment we may assume that the axis of B is at an inclination to the crank pin of one in ten, the screw C cut with twenty threads to the inch, and the head slotted with five notches 72 degrees apart; then the revolution of the screw C one notch will move B one-hundreth of an inch axially and adjust the bearing towards or from the crank pin one-thousandth of an inch.

The rigidity, accuracy, and delicacy of adjustment of this bearing are shown in the marine form of rod, Fig. 164. The bolts of the cap are drawn up tight and locked, thus holding the cap and the rod metal to metal, making it in effect as rigid as a solid-end rod. The adjustment of the bearing is then made as frequently and as delicately as desired. For large marine engines, mechanism for working the adjustment could be carried to a point near the cross head, so that the bearings of both the crank pin and the cross-head pin could be adjusted with the greatest facility even while the engine is in motion. The more massive the rod the greater are the advantages of a rigidity that does not affect the ease and delicacy of adjustment.

The end pressure on B from the load is the resultant of the angle of inclination used less the sum of the frictions on the two opposite surfaces of the wedge. Proportions can be used that will result in a practical equilibrium so far as the end motion of B is concerned.

Fig. 162 shows the application of the adjustment to an ordinary valve rod in which the adjustable parts are placed in the rod in such a manner as to have the wear of the bearings affect the centre to centre length the least possible. The variation is here the dif-

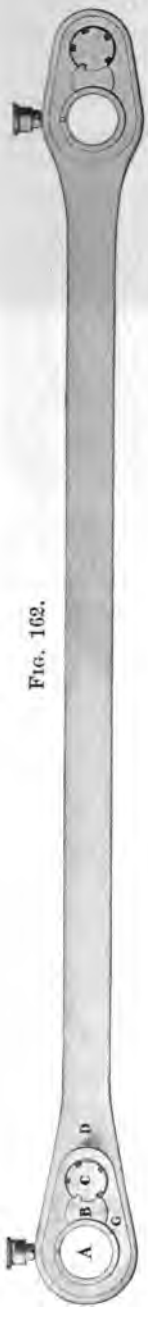

Fig. 162.

Fig. 163.

Fig. 164.

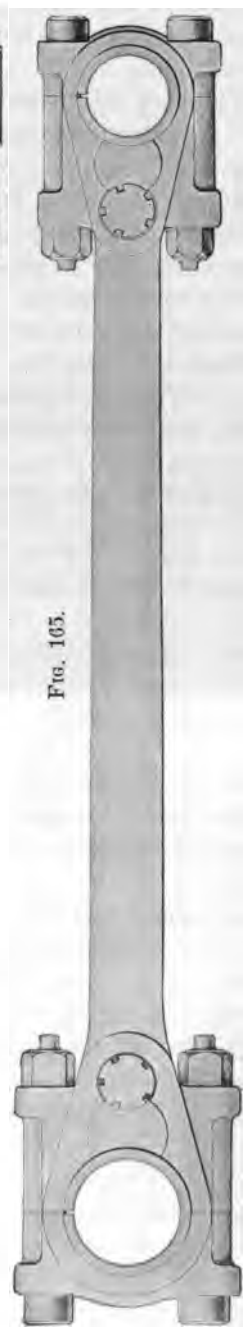

Fig. 165.

ference in the wear of the two bearings instead of the sum of their variations, as is the case in the usual arrangement of the adjustments.

The very rigid form of this bearing, together with its delicate and accurate adjustment, makes it suitable for minute adjustments required in stamping presses.

It will be noticed that the adjustment of the bearing is a parallel motion with large bearing areas, accurate surfaces, and little or no tendency to get out of adjustment, either from long use or faulty manipulation. The delicacy of the adjustment, the mechanical accuracy of the bearing, and the decrease in the cost of manufacture over the ordinary designs will be evident to shop men. The bushing is of the best form for securing accuracy of form combined with economic manufacture. The bushings can be renewed at a comparatively small expense, when the original length of the rod will be exactly restored.

No. 889.*

PULLEY-PRESS VALVE.

BY FRANCIS H. STILLMAN, NEW YORK CITY, N. Y.
(Member of the Society.)

A Large Press Operating Valve.

THE valve shown and described in this paper is believed to be one of the most elaborate ever used to operate the motions of a single hydraulic press.

It is evident that the conditions of working which would call for such a valve as shown in Figs. 166 and 167 must be special, and of a complicated nature. The conditions were that of serving quickly a press having cylinders working from six directions, and aggregating about 2,500 tons.

The time of a complete series of motions, including the time required to put the work in the dies by hand and to remove the work from them, is from $\frac{1}{4}$ to $\frac{1}{3}$ of a minute, if such a speed is desired.

It is to be understood that in addition to the press cylinders used in doing work, there are automatically operated cylinders for drawing the rams back, connected to the accumulator without any intervening valves.

The work to which these presses are devoted is the manufacture of the American Pulley Company's all-steel pulley rims, which are put into the press in half-circles, which are first gripped and crowned (if so wanted) by four horizontal cylinders. Then two vertical cylinders working in opposite directions turn the edges over—one at right angles, to form the middle stiffening section to which the arms are rivetted; the other produces the beaded edge. These are two of the special features of these pulleys, as shown by Fig. 168.

Elevations and sectional drawings of one of these presses, taken from a German mechanical paper, are shown as Fig. 169. These

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

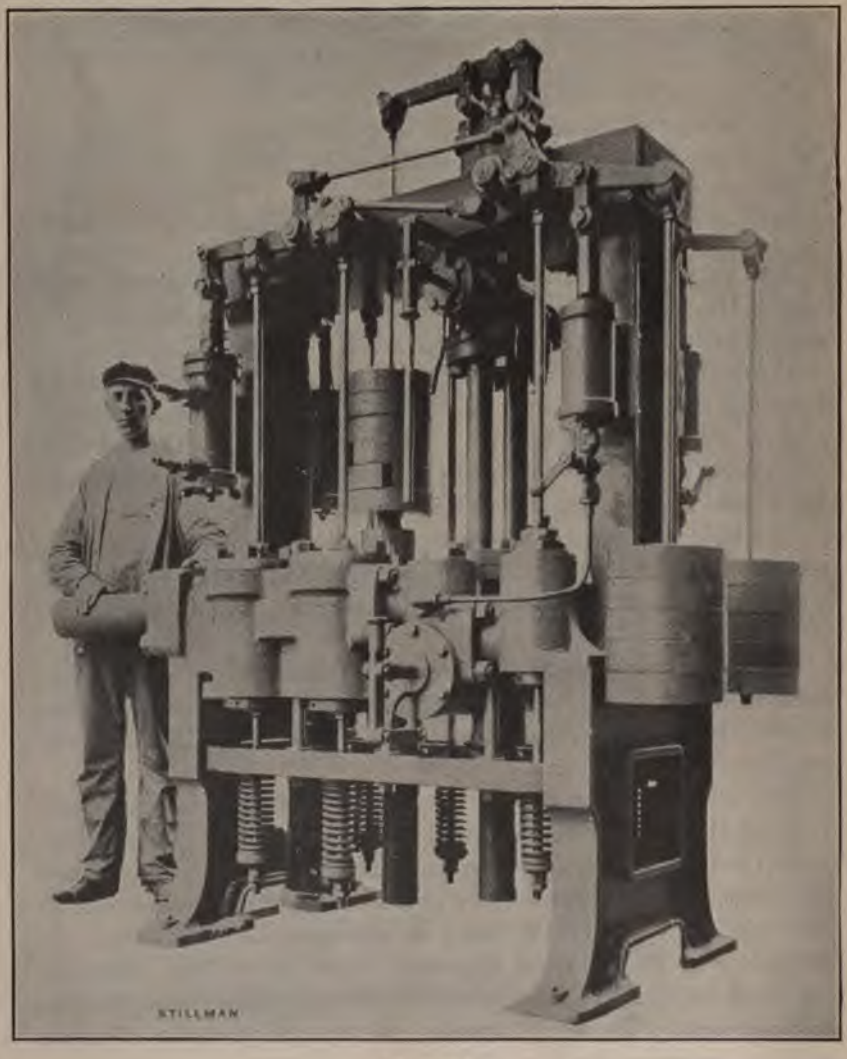

FIG. 166.

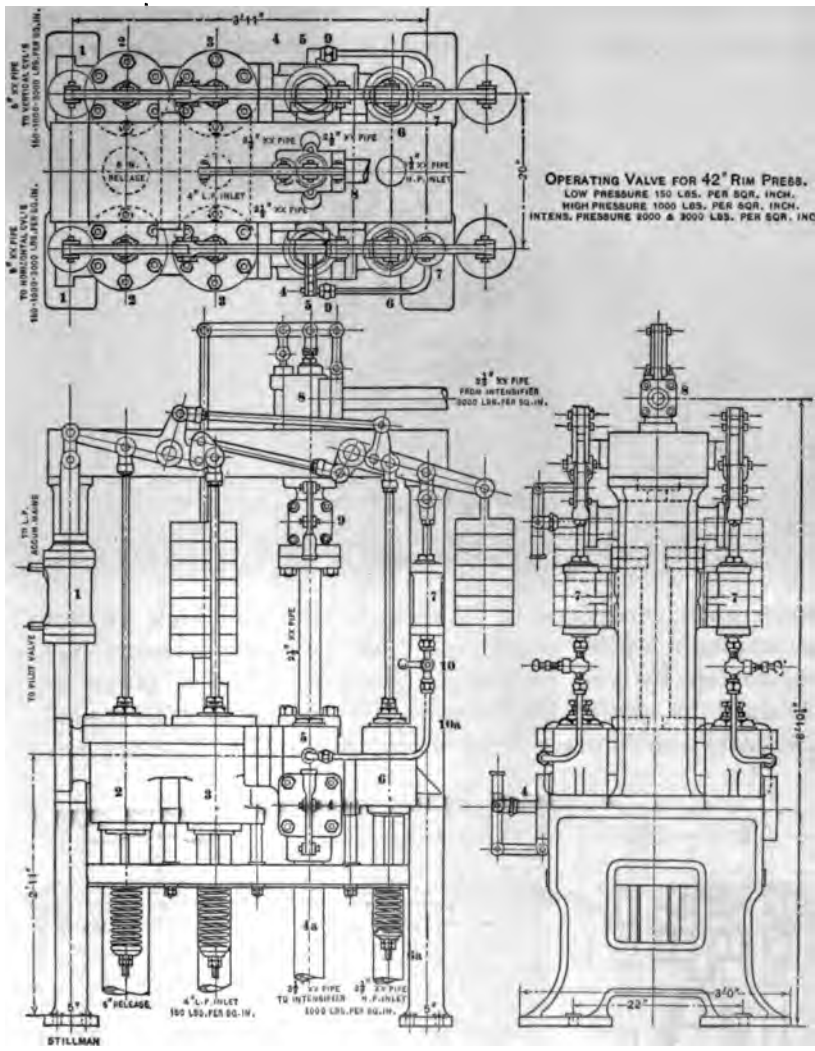
OPERATING VALVE FOR 42" RIM PRESS.
LOW PRESSURE 150 LBS. PER SQR. INCH.
HIGH PRESSURE 1000 LBS. PER SQR. INCH.
INTENS. PRESSURE 2000 & 3000 LBS. PER SQR. INCH.
STILLMAN

FIG. 167.

are clearer than any drawings of the press which were made by us.

The motions of this press when doing no work must obviously be a considerable part of the whole, while the motions requiring the heavy pressure are very short. The economy of operating

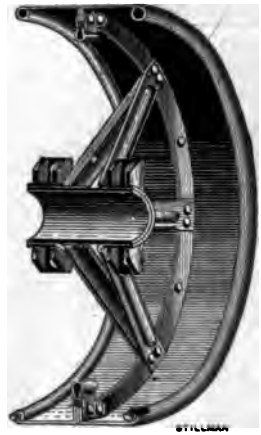

FIG. 168.

under such conditions is obtained by low and high pressure accumulator service of 150 and 1,000 pounds per square inch, augmented by two intensified pressures. These latter are obtained by one variable intensifier working at 2,000 pounds and 3,000 pounds pressure, as shown by Fig. 170. The change of

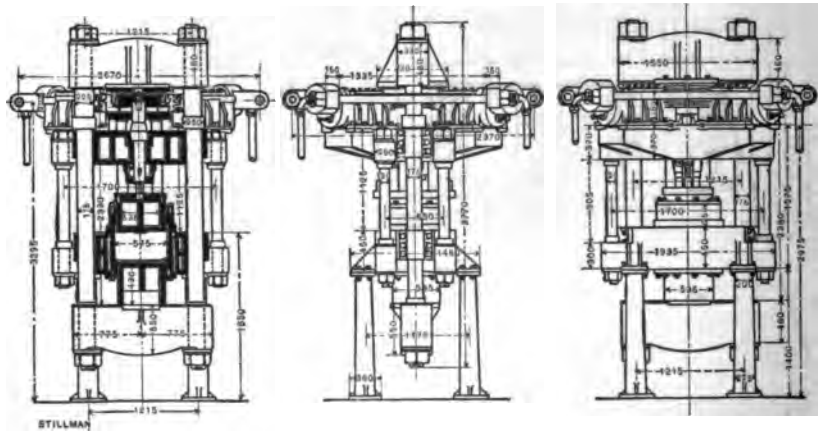

FIG. 169.

FIG. 170.

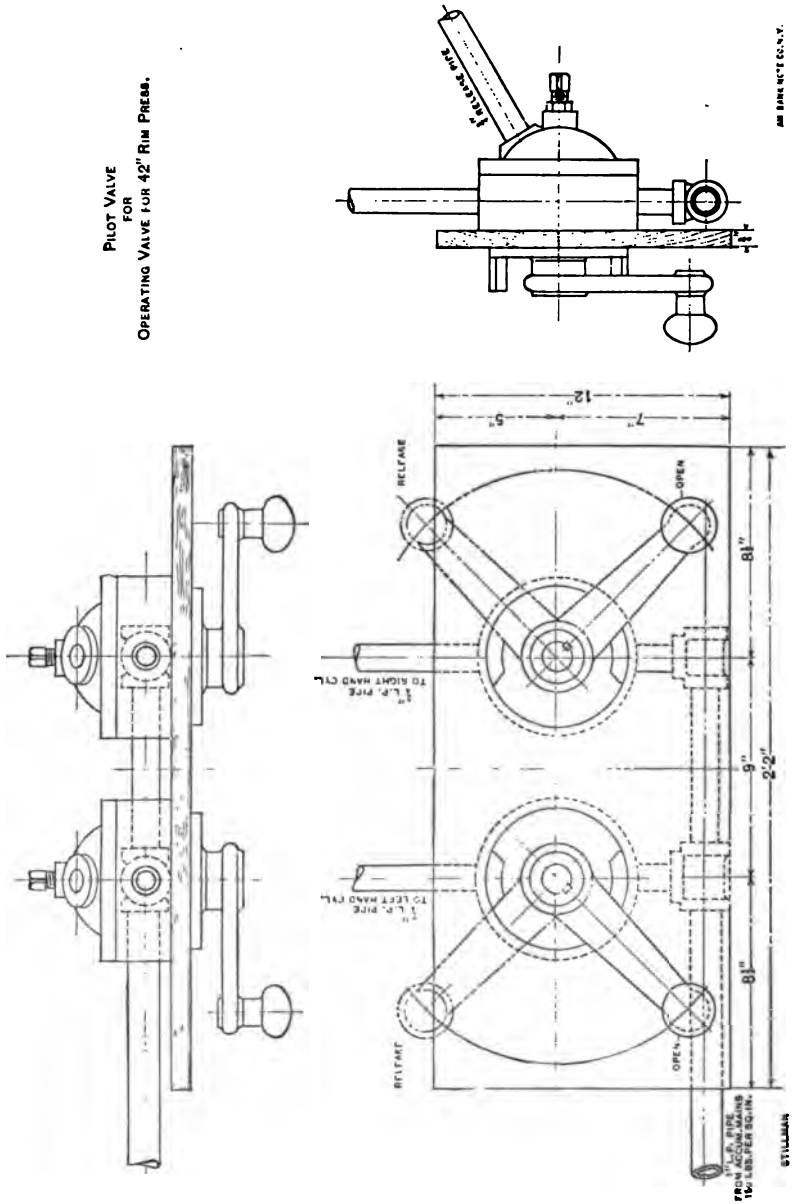
PILOT VALVE
FOR
OPERATING VALVE FOR 42" RIM PRESS.
RELEASE
OPEN
12"
7"
5"
81"
9"
2'-0"
STILLMAN

FIG. 171.

PILOT VALVE
FOR
OPERATING VALVE FOR 42" RIM PRESS.

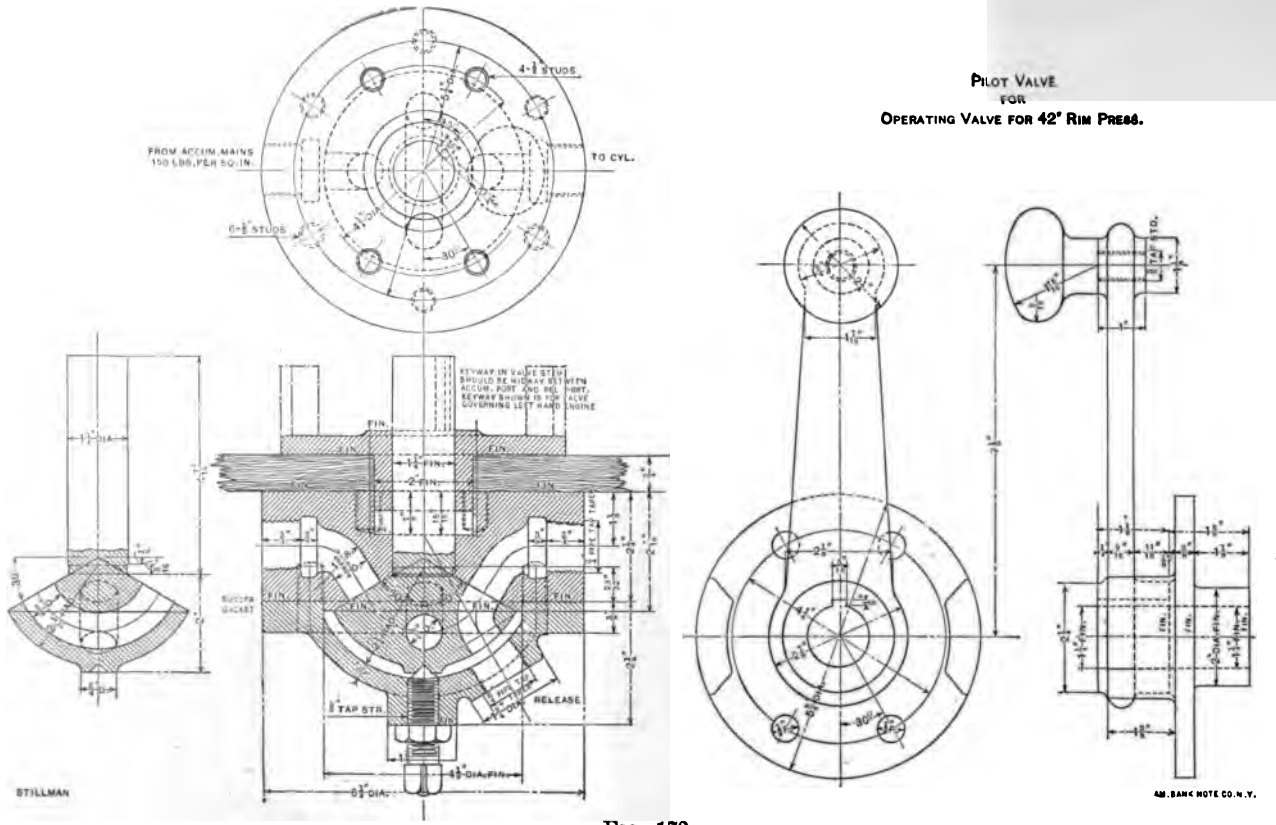
4-⅞ STUDS
FROM ACCUM. MAINS
150 LBS. PER SQ. IN.
TO CYL.
6-⅞ STUDS
KEYWAY IN VALVE STEM SHOULD BE HIDWAY BETWEEN ACCUM. PORT AND REL. PORT. KEYWAY SHOWN IS FOR VALVE GOVERNING LEFT HAND ENGINE
FIN.
RELEASE
STILLMAN
AM. BANK NOTE CO. N.Y.

FIG. 172.

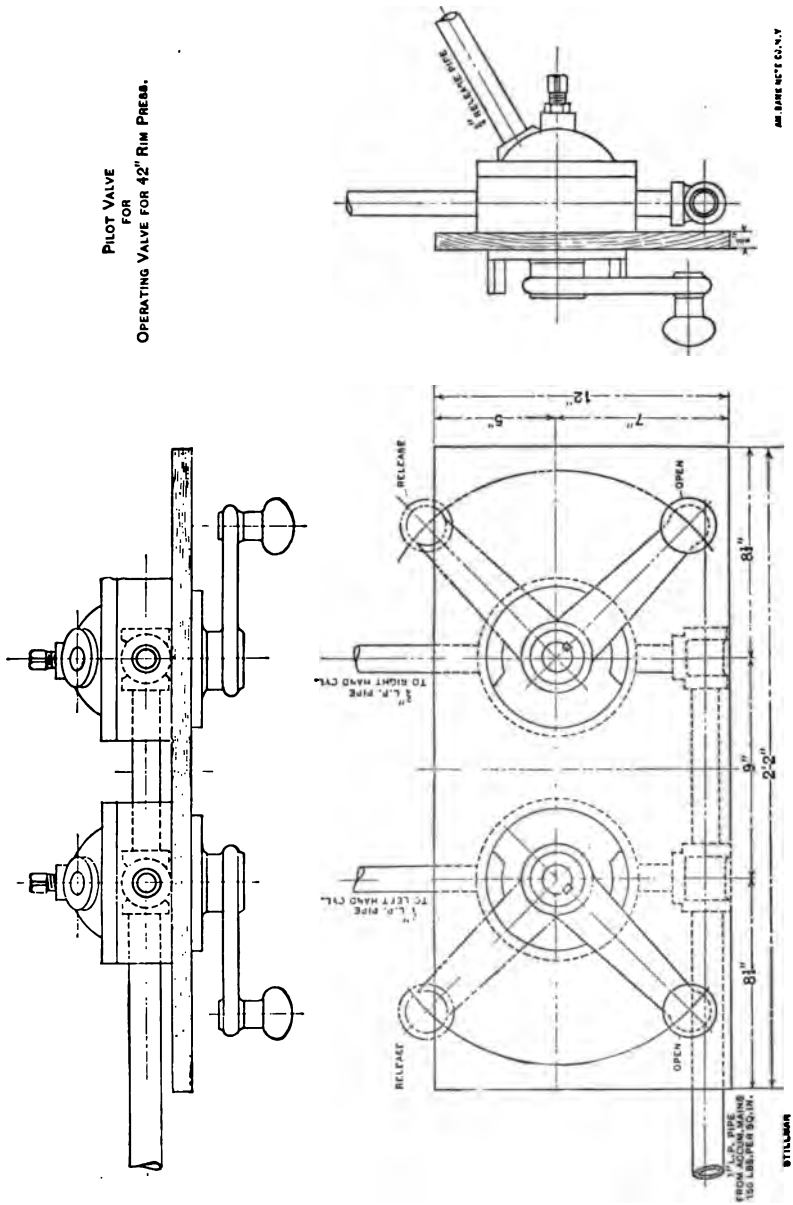
PILOT VALVE
FOR
OPERATING VALVE FOR 42" RIM PRESS.
RELEASE
OPEN
12"
7"
5"
8½"
9"
2'-2"
RELEASE
OPEN
8½"

FIG. 171.

PILOT VALVE
FOR
OPERATING VALVE FOR 42" RIM PRESS.

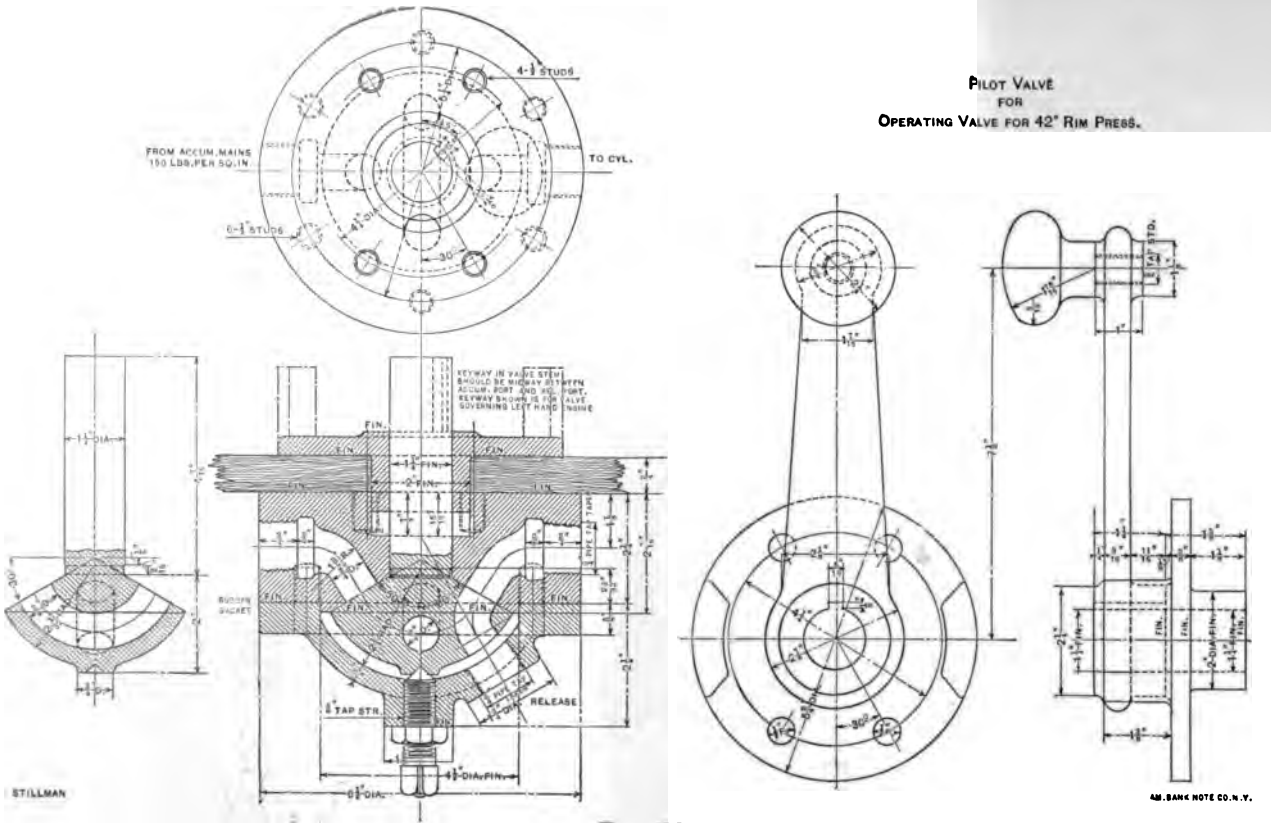

FIG. 172.

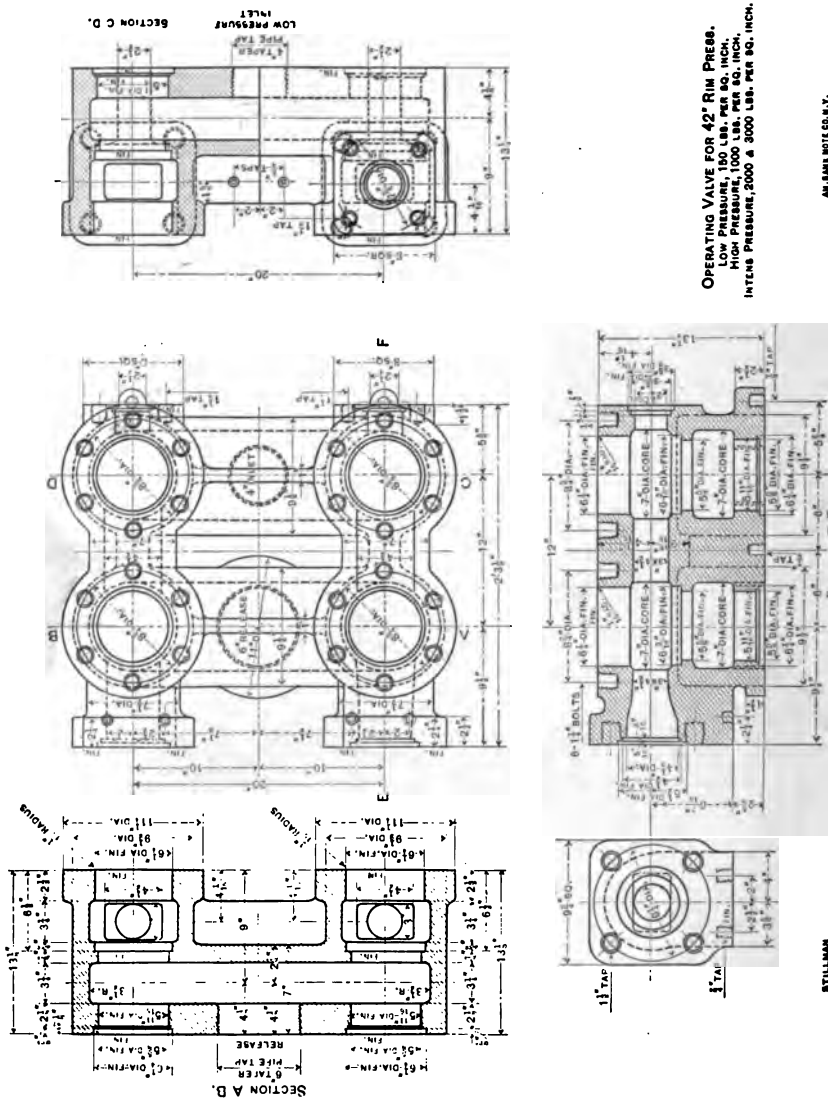
OPERATING VALVE FOR 42" RIM PRESS.
LOW PRESSURE, 150 LBS. PER SQ. INCH.
HIGH PRESSURE, 1000 LBS. PER SQ. INCH.
INTENS PRESSURE, 2000 & 3000 LBS. PER SQ. INCH.
AM. BANK NOTE CO. N.Y.
SECTION C D.
LOW PRESSURE INLET
SECTION E F.
SECTION A B.
STILLMAN

FIG. 178.

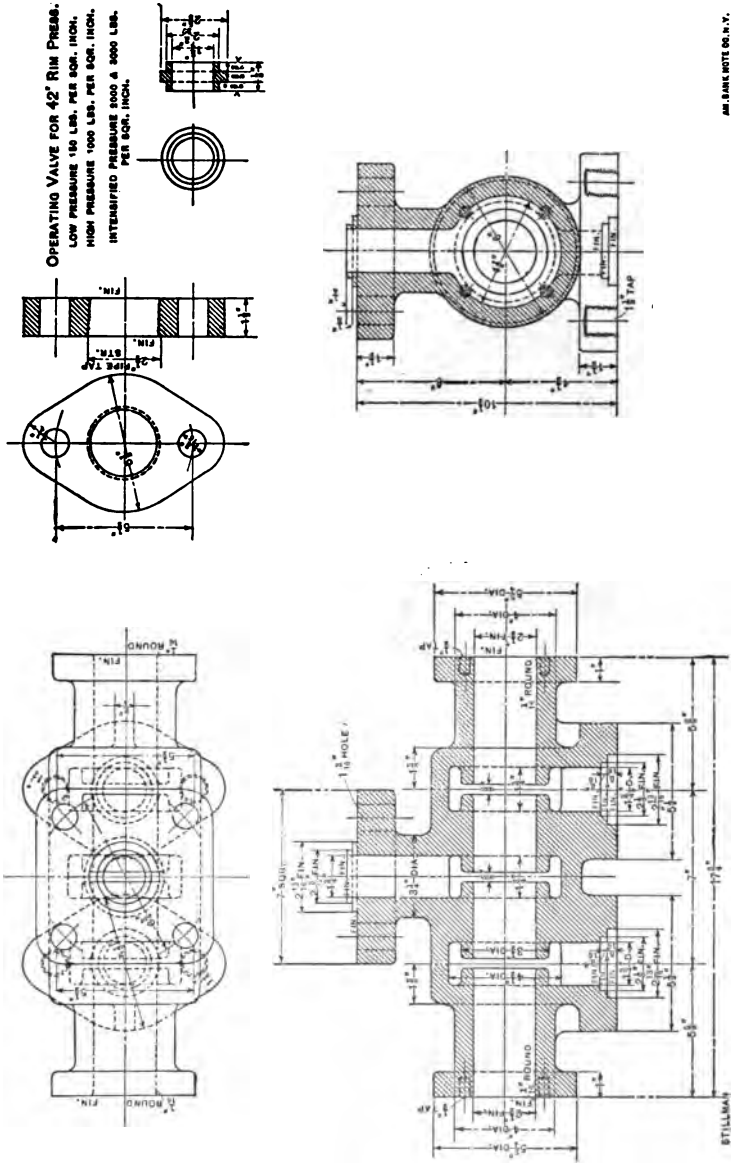
OPERATING VALVE FOR 42" RIM PRESS.
LOW PRESSURE 150 LBS. PER SQR. INCH.
HIGH PRESSURE 1000 LBS. PER SQR. INCH.
INTENSIFIED PRESSURE 5000 & 8000 LBS. PER SQR. INCH.
AM. BANK NOTE CO. N. Y.
STILLMAN

FIG. 174.

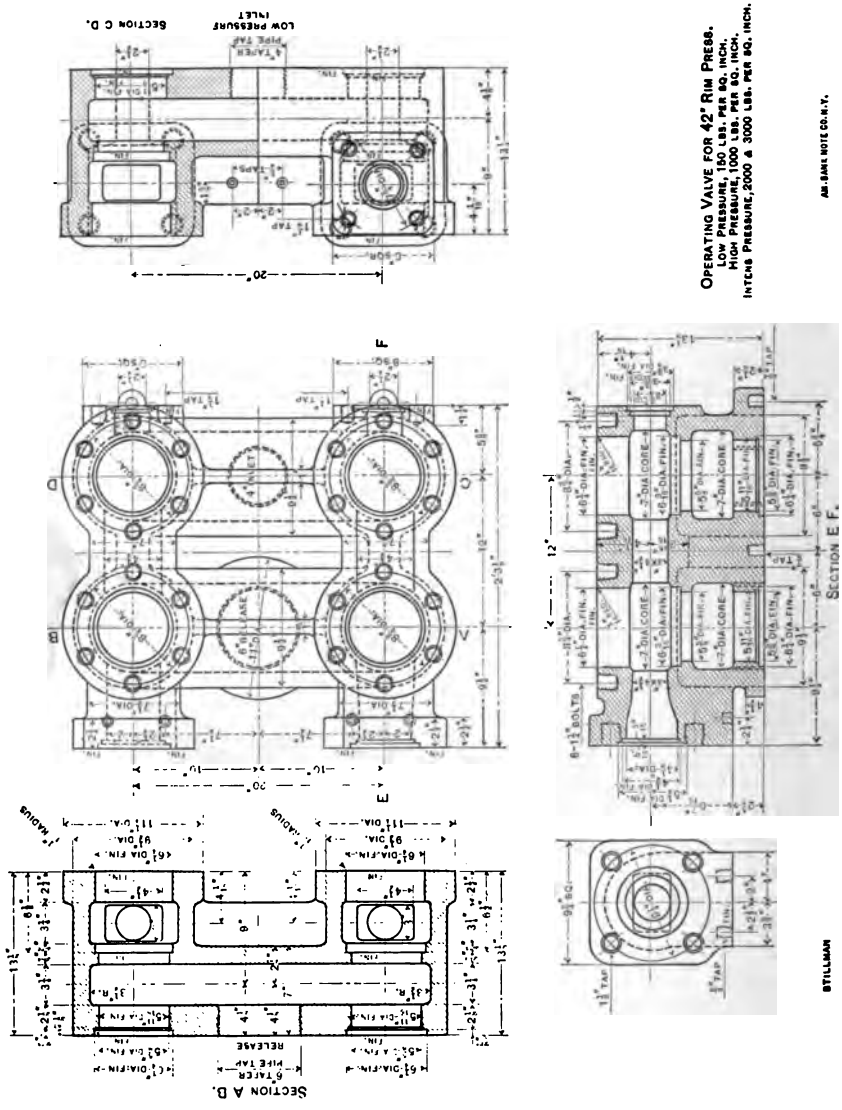
OPERATING VALVE FOR 42" RIM PRESS.
LOW PRESSURE, 150 LBS. PER SQ. INCH.
HIGH PRESSURE, 1000 LBS. PER SQ. INCH.
INTENS PRESSURE, 2000 & 3000 LBS. PER SQ. INCH.
AM. BANK NOTE CO. N.Y.
SECTION C D.
LOW PRESSURE INLET
SECTION A B.
SECTION E F.
STILLMAN

FIG. 178.

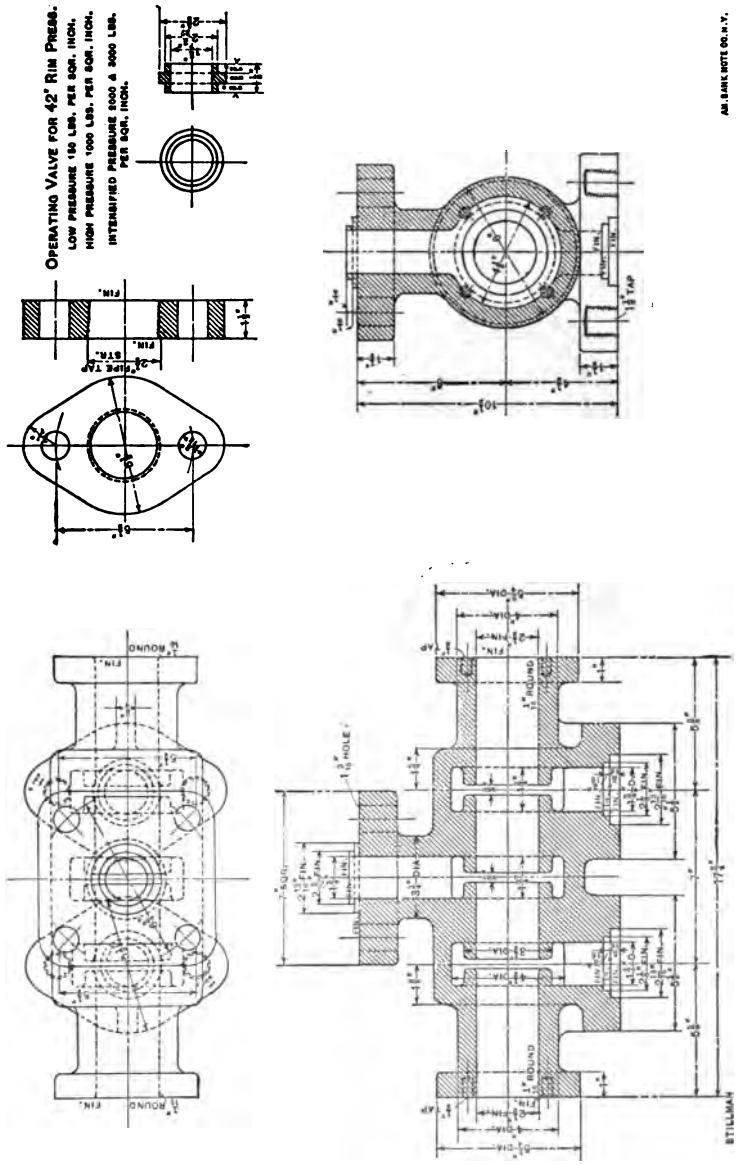
OPERATING VALVE FOR 42" RIM PRESS.
LOW PRESSURE 150 LBS. PER SQR. INCH.
HIGH PRESSURE 1000 LBS. PER SQR. INCH.
INTENSIFIED PRESSURE 2000 & 3000 LBS. PER SQR. INCH.
AM. BANK NOTE CO. N.Y.
STILLMAN

FIG. 174.

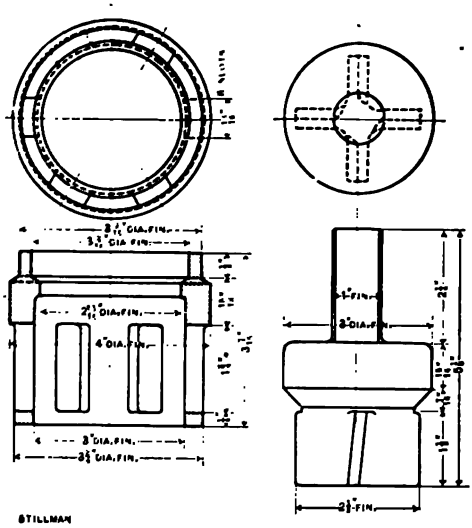

FIG. 175.

pressure obtainable by the latter is secured by locking an intermediate ram either to the high-pressure ram or low-pressure cylinder.

This press-controlling valve is started in motion and stopped and returned to the starting position by means of auxiliary valves shown by Figs. 171 and 172. One of these valves is placed in connection with each side of the main valve, which is in nearly all respects double, one side governing the vertical and the other the horizontal cylinders. In service a good operator can handle both of these starting valves at practically the same time, as actual working condition will retard the vertical pair of cylinders enough for the horizontal ones to grip the work before the bending action of the former begins.

These starting valves are, as the cut shows, a disc valve having large spherical metallic seats. These throw the low-pressure accumulator service to differential double-acting low-pressure operating cylinders.

The various valves and cylinders of the main combination and the sizes of pipe connections are as follows, as per Fig. 167:

1. Double-acting, low-pressure cylinder pipe connection (1*a*), ¾ inch.
2. Low-pressure inlet valve (2*a*), 4 inches.
3. " " release valve (3*a*), 6 inches.
4. " " intensifier cut-out valve (4*a*), 3½ inches.
5. " " check valve.
6. High-pressure inlet (6*a*), 3½ inches.
7. " " actuating cylinders, 1½ inches.
8. " " intensifier valve, 2½ inches.
9. " " " cut-out valve, 2½ inches.
10. " " throttling or cut-out valve, ½ inch.
11. Press connection, 5 inches.
12. Pilot or auxiliary valve, ¼ inch.

In operating, the low-pressure accumulator service is first thrown by the auxiliary valve to the cylinder No. 1. The piston of this cylinder is connected, as shown, by an interconnected system of bell-crank levers to the various valve spindles, and helps to control them. When the piston of the cylinder is pushed up, the valve spindle of *B* is seated and that of No. 2 is raised; this admits the low-pressure service to the press cylinders. When the low-pressure accumulator service has nearly equalized itself, the spindle No. 6 is lifted by the cylinder

No. 7, which first seats the low-pressure spindle No. 2; the connection to the cylinder No. 7 being through the valve 10 and pipe 10*a* leading from the upper part of the check valve No. 5. The opening of the valve No. 6 admits the 1,000 pounds intensifier service to the press, and if the valve No. 9 is opened and the high-pressure service is maintained long enough to raise the counterbalancing weight, the high-pressure intensifier service will be opened to the press, and this pressure will be either 2,000 or 3,000 pounds to the square inch, depending upon the position of the intermediate ram of the variable intensifier.

To release the press, the auxiliary valve is thrown backward, releasing the fluid in the lower end of the cylinder No. 1, which opens the valve 3.

The series of motions of the valve can be stopped at any time by reversing the auxiliary valve. Should the high-pressure intensifier service not be wanted because of light work being in the press, it is cut out entirely by placing the valve piston of No. 9 valve at an intermediate position. Should the work not require the 1,000 pounds pressure to the intensifier service, similar action with the valve No. 4 will cut that out.

While the valve as a whole seems complicated, a consideration of the construction of the single spindle valve shows that the details of the main valves are simple. The spindle of the valve is of the same diameter at each end, it being thus completely balanced, except that part of the seat which is in direct metallic contact, and this is counterbalanced by the compression upon the springs shown in Fig. 167. Fig. 173 shows a section of the body of valve No. 9.

The valve chambers of all valves above 2½ inches are made of steel castings. Fig. 174 shows the largest of the three composing the main valve deck, and these are bushed with bronze at the seats. The valve spindles are all made of bronze. A feature of the check valve is made clear by Fig. 175. This shows the sleeve and valve, which are so arranged that the currents of water through the cage will give a rotary self-cleaning motion to the valve.

All of the vertical valves in this combination are of our balanced spindle type.

No. 890.*

A SPECIAL FORM OF BORING AND FACING MACHINE.

BY WALTER S. RUSSEL, DETROIT, MICH.
(Member of the Society.)

THE first illustration accompanying this paper presents a tool gotten up by the writer to meet a special emergency. It is really a portable machine, simply resting upon the floor of the shop, with a slight excavation below for the driving-shaft and pulleys. The cylinder, shown in Fig. 176 with the machine, and one of whose flanges has just been finished, is 13 feet in diameter and 3½ feet high, and weighs 3½ tons. The flange surface is 4½ inches wide. The mill, with its four cutters, finished this surface, clearing away ¾-inch in depth, to insure a good surface, in slightly over two hours. An internal flange about half way down the cylinder is also faced by blocking up the casting from the bed-plate of the machine, instead of clamping it directly to the bed-plate, as shown in cut.

The mill is made up of a cylinder, on which is mounted a revolving plate holding four cutting heads. The upper edge of the cylinder, concealed from view in cut, projects inward to form a flange; the lower edge projects inward also to form seats for the brackets of the driving mechanism, and outward to form a base to which castings to be finished are secured.

The absolute necessity for an extra machine to do this class of work, due to the fact that our foundry had gotten ahead of the machine shop in the progress of manufacture of a lot of this large cylinder work, was the excuse for the conception of this machine, when it became known that a mill which could do this work could not possibly be obtained within several months. The drawing for the machine was made, and given to the pattern-maker on November 16th. On December 15th, twenty-five working days after, the first casting was placed on the

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

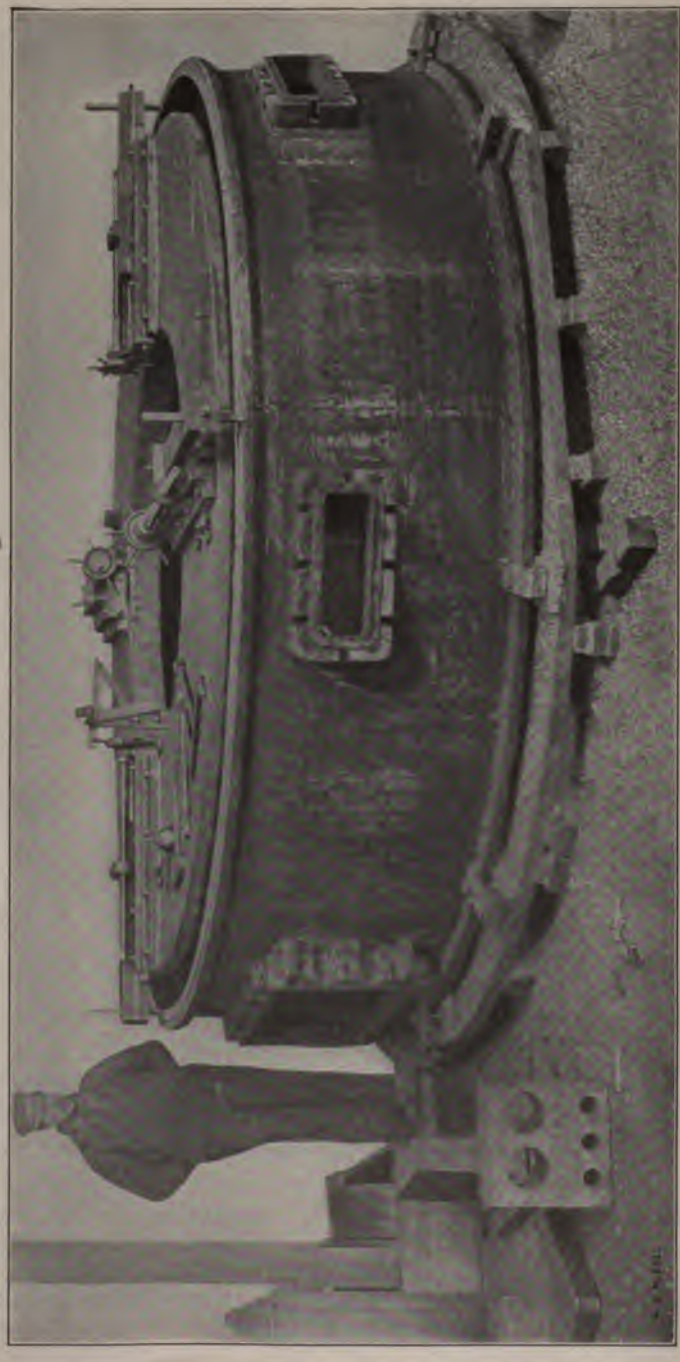

FIG. 176.

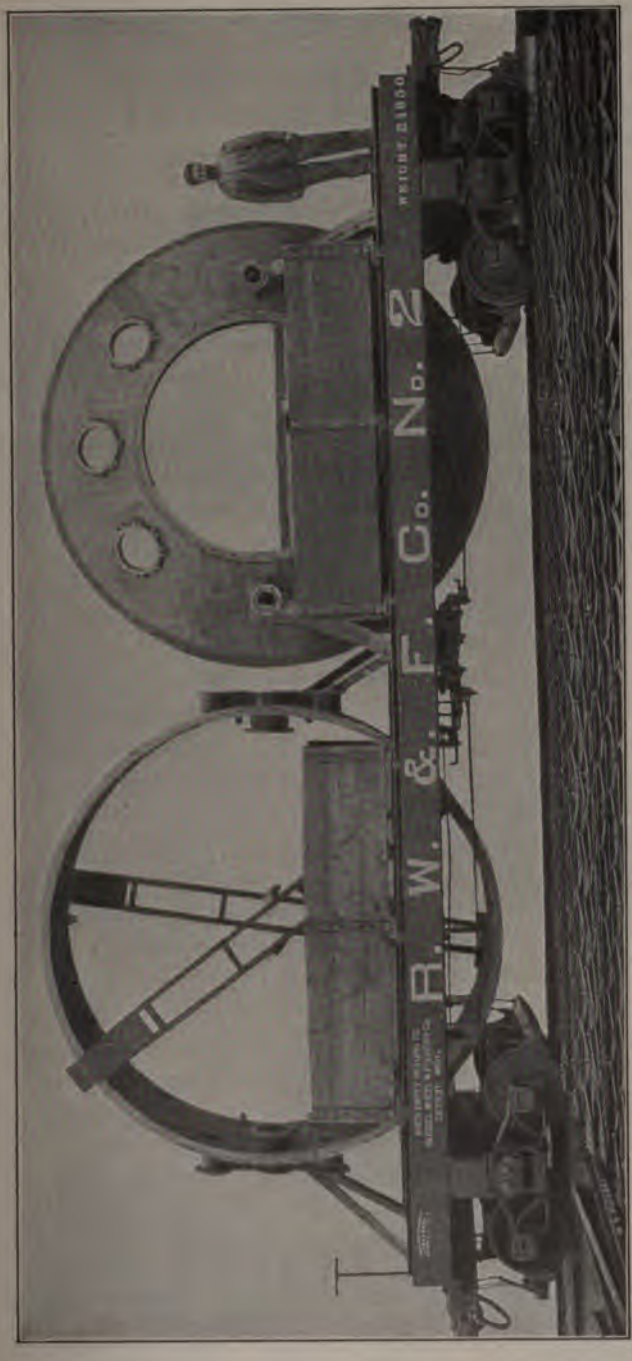

Fig. 177.

machine, and with only two cutters the first flange was finished in three hours.

The complete machine weighs 34,000 pounds, and costs $1,300. As said above, it is portable, and can be rolled into a corner or outside of the shop, if not used.

At first glance, the range of work seems limited, but the cutting heads shown on the plate can be removed and fastened to brackets properly fitted to the vertical cylinder of the machine, and the castings to be machined secured to the revolving plate, giving a possible great variety of work. Again, a bridge, holding the tool, supported on legs and secured to the main frame at a moderate expense, will make a rough but very powerful tool for large work.

Fig. 177 shows one of the cylinders which was finished on this mill, and its cover, loaded on a specially constructed car, as the diameter of the castings would not allow of their transportation on an ordinary flat car.

No. 891.*

A METHOD OF PREPARING AND BALING COTTON IN ROUND BALES OF UNIFORM LAP. †

BY JOHN R. FORDYCE, LITTLE ROCK, ARK.
(Member of the Society.)

ALTHOUGH this article on the "Baling of Cotton in Round Bales of Uniform Lap" is the result of the Society's request for information and reports from the members who are engaged in creative work, this process is not so much of a creation as it is of an adaptation of the well-known and tried methods of handling cotton at the mills to the Southern gin houses.

Having stood the test of over a hundred years of constant work, these mill methods and machines are, through evolution, almost perfect, and in adapting mill methods and machines to gin-house work, I have made only such changes as different requirements or less skilful handling seemed to require.

This machine and method are the result of six years of study and work, during which time I have built six different machines, each successive one an improvement over the other. I have designed, watched the building, the loading on cars at the shops, and the far more difficult unloading on a country siding, with only the most primitive means; the erecting, and then the days and months of operating, under the most difficult conditions which different classes and conditions of cotton would bring about. I have unrolled the bales and watched the effect on the cotton of various changes which seemed necessary. I have followed the bales to the mills, and have heard their condemnation and their praise, and at first the praise was not frequent.

The machines which these drawings show are the last which I have designed and they are now being built. The photographs

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† For other discussions on this subject, consult *Transactions* as follows:
Volume XIX., paper 785, page 812: Lowry, Geo. A., "Ginning and Baling Cotton from 1798 to 1898."

show last year's work, but they are near enough like the present ones to be of use in helping to understand the present one.

A brief description of the process of handling cotton at the mills will enable you to understand the objects and the need for the round-bale method of handling cotton. The first treatment of cotton is the mixing of the different grades to form a uniform stock. The next is beating out the dirt and making the cotton up into round laps. These laps are taken to the cards, and in them the fibres are drawn out, straightened, arranged parallel to one another, and then formed into a loose yarn. After that the yarns are combined and subjected to further drawing and twisting together until the thread is made.

The mixing of the square-bale cotton is now done by hand by breaking up the bales and spreading one grade over the other—and a long and tedious process it is.

The mixing of cotton put up in round bales is done by machines, which several of our cotton-machinery manufacturers are now building. One is shown in Fig. 178. Several round bales are mounted on a moving belt and unwound together. These bats, one above the other, are beaten together by a rapidly revolving beater, thus mixing them much more thoroughly than can be done by hand. The mixed bat is wound up into a lap, and, if desired, two or more of these laps can be mixed, so that any degree of mixing can be obtained.

It is customary when working up square-bale cotton to form three round laps by breaking and feeding the cotton into the first, and then beating this up and forming the second, and then the second into the third. The third lap goes to the cards.

All this beating and lapping is to get out dirt, motes, and trash, and to form laps which do not vary greatly in weight per running yard.

The object of the round-bale method is, first, to make automatic or perfect mixing possible; second, to furnish a bale which is put up, kept, and handed over to the mills in such a clean state that so much cleaning is not necessary, thus avoiding the expense, waste, and damage to the cotton.

To accomplish these results, the bales must be uniform in grade, the bats must be as nearly uniform in weight as is possible to make them, and the compression of the bales must be such that the cotton is not knotted or caked by over-pressure, but yet dense enough to make it a desirable package for transportation.

Following the round and square bales back from the mills to the plantations, and contrasting them, we find that the round bale arrives at the mill entirely protected by the bagging, without wires or hoops; clearly marked, so that it can be traced back to its origin. The tare is only one instead of six per cent. as in the old square bale with its iron hoops and gaping coarse bagging which does not protect.

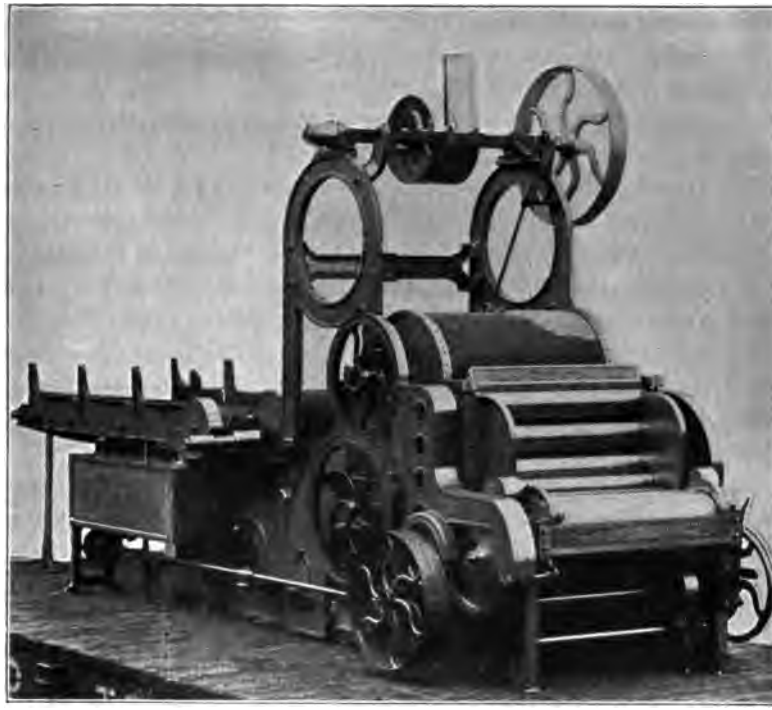

FIG. 178.—ROUND-BALE OPENER AT THE MILL.

The waste in dirt, imperfect seed, and damaged lint amounts to five per cent. more in the square bale. In the round bale all of this waste is left at the gin house, so that no freight has been paid on it, nor has the mill paid for it. The grade of the cotton has been improved so much that the owner realizes more for what he sells. The round bales are put on a mixer and the resulting laps can go directly to the intermediate lapper, thus saving the cost of the automatic feeder and breaking lapper and using only about half of the power of the picking-room, increasing the production and decreasing the mill waste.

Transporting and Warehousing.

Next in importance to having a perfect bale for the mill, comes that of having a bale which suits both the transportation lines and storage companies. At present the crop is about 10,000,000 bales. Of this 65 per cent. is exported, 20 per cent. worked in Northern mills, and about 15 per cent. worked in Southern mills. The crop is gathered and baled in about three months, while it takes twelve months to work it up.

The round bale has a density of 35 pounds per cubic foot, while the square bale has only 25 when compressed. Ships, cars, and warehouses will hold about 40 per cent. more round than square bales of cotton.

The round bale being better covered, and having all air pressed out of it, makes the fire risk less. Owing to the method of making a square bale, the air mixed with the fibre is pressed in the bale, so if the cotton catches fire, the spark will eat its way into the bale and burn for weeks undiscovered. Last year the great Hoboken fire was started by a square bale of cotton bursting into flames on the dock. Fig. 179 shows a fire tug trying to put out the fire on one of the few lighters which were saved. Every year cargoes of square bales catch fire at sea, and great damage results.

The above considerations have caused reduction on ocean freight of 25 per cent. in favor of round bales. The insurance in transit and storage is 35 per cent. less than for square bales.

At the Gin.

The round bale is made and pressed simultaneously. The square bale is made at the country gin, and then taken to a compress point, and its bulk reduced by powerful presses weighing about 300,000 pounds. The round-bale press weighs only about 15,000 pounds, and its bales are denser than the compress bales by about 10 pounds per cubic foot. The secret of its work is that it presses the cotton in detail, forcing out the air as it goes, and then holds what it gets, while the square bale is crushed down all at once by the powerful ram of the compress. The entrapped air is compressed but not expelled. The round-bale press requires more power to run it than a square-bale press at the country gin, but the cost of the covering for a round bale is a great deal less than the covering for the square bale, so that the cost of a completed bale is only slightly greater than that of the square bale.

FIG. 179.—THE HOBOKEN FIRE—THE "BREMEN" IN DISTANCE, FIRE TUG AND BURNING LIGHTER IN FRONT.

The ginner who operates the press becomes a compressor, and receives the rebate paid by the railroad companies for compressed cotton.

Bales are sampled as they are made; the samples numbered to correspond to the number and name on the bale, and guaranteed to represent the bale. A better price can be paid the grower, because his bale contains more cotton and less tare.

By all of these savings it is estimated that about $4.00 per 500 pounds, or $40,000,000 per year, could be saved to the South were this system used exclusively.

The compress owner and others interested in the old square bale are, of course, doing all in their power to retard the round-bale growth, but the advantages of the round-bale system are real, and in the end must prevail.

The Process.

The cotton fibre grows as a protection to the seed of the plant. It covers the seed, and several locks of fibre and seed are enclosed in a woody hull. When ripe, the hull splits open, and the soft milky fibres are dried and blown out by the wind. The fruit near the ground on the stalk ripens first, and that above in succession until the last is killed by frost. For this reason, cotton cannot be gathered all at once, but the fields must be picked over and over again by a discriminating hand.

Dirt, leaves, hulls, etc., are picked along with the fibre and seed; sometimes the cotton is wet. Upon reaching the gins, it is necessary to dry and clean this seed cotton, and then tear the fibre loose from the seed. This is called ginning, and the gin machinery, with some improvements in detail, remains just where Whitney left it at the beginning of the last century. In brief, a gin is a gang of circular saws 10 inches in diameter, mounted about $\frac{3}{4}$ of an inch apart on a shaft. These saws revolve between ribs which are set so close that a fully matured seed cannot be drawn between them. The teeth, shaped something like a rose thorn, drag off the fibres. A revolving bristle brush takes the fibres off of the teeth, and makes air-pressure enough to blow the lint through a pipe to the condenser. An average gin plant consists of four gin stands of 70 saws each, feeders, flues, condensers, and press, engine, and boiler.

The machinery described in this paper begins at the common

flue of the gins, and continues through the press, or final gin operation.

Fig. 180 is a cross section through the condenser, lint receptacle, bat former, and press.

Referring to the drawing, *A* is the flue through which the cotton is blown from the gins to the condenser; *B* is a drum covered with wire cloth; air and dust escape through the meshes of this, and the cotton is carried over as a thin bat to the rollers *C* and *D*,

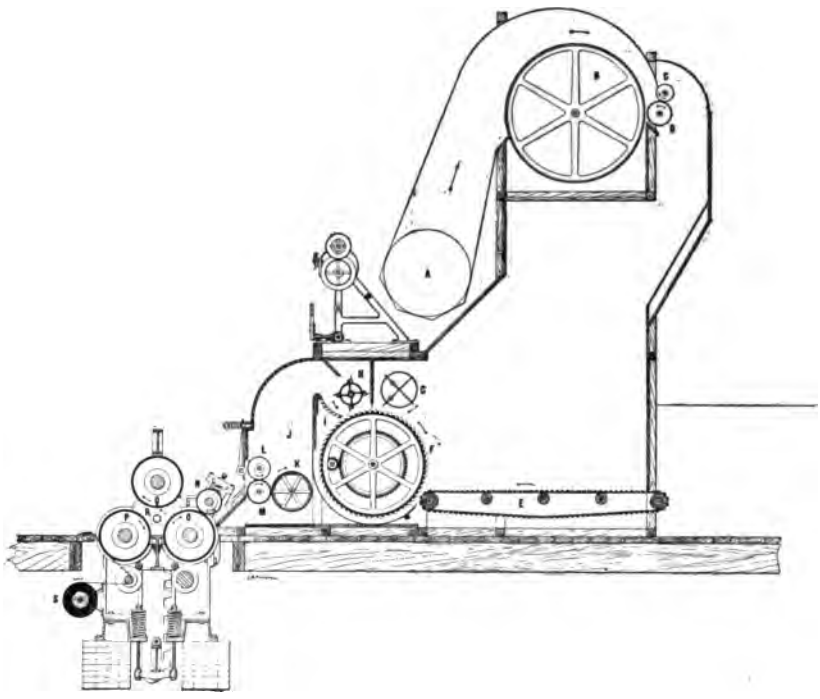

Fig. 180.

which wipe it off the drum and press out some of the remaining air, and then drop it on the apron *E*, at the bottom of the cotton receptacle. This apron moves slowly up to the revolving picker wheel *F*, which wheel is going rapidly, and carries the cotton up and under the roller *G*. This roller has teeth, which protrude when they get opposite the picker wheel and recede on the opposite side. The function of these teeth is to knock back and prevent too much cotton coming over at a time, and to keep the cotton from getting thicker on one side than the other; they are con-

trolled by eccentrics on either side of the machine. A beater *H* brushes the cotton off of the picker wheel, and throws it over into the bat former, *J*. This wheel makes a separation of the motes or imperfect seed which the gin saws have drawn through the ribs; these motes fall through the grating *I*, and are carried by the wheel back under the apron *E*, where they are cleaned out at intervals. The cleaned lint cotton in small flakes is thrown over, and falls on the rollers *K* and *L*. The roller *K* is made of wire cloth, to allow dirt and motes to fall through it. The cotton is drawn between these rollers, and then between rollers *L* and *M*, where it receives a preliminary compression. These rollers detect the thickness of the bat, and, if it is too thick or thin, a shifter is moved which either slows or quickens the speed of roller *K*, the picker *F*, and the apron *E*. In this way the thickness of the bat per yard is kept very nearly uniform.

The gins are continually choking and stopping, and the supply of cotton, if taken direct from them without holding a reserve supply in the receptacle, will cause at times a variation of 25 per cent. in the weight of the bat.

The speed-regulating mechanism is so arranged that it will stop the feeder if the speed gets too fast, which would indicate, of course, that there was not enough cotton in the hopper to make a standard-weight bat. It is better to have a break in the lap than to have it too thin, although it is usual to stop the press also, and thus avoid breaking the bat.

The bat on leaving rollers *L* and *M* is drawn between the small roller *N* and the press roller *O*, thence around the core *R*. The surface of the press rollers are going about 20 per cent. faster than the surface of the rollers *L* and *M*, thus the fibres are straightened out to a certain extent.

The bale is made between the press rollers *O*, *P*, and *Q*, and around the core *R*. As the bale grows in diameter, the roller *Q* rises.

When the bale is finished, the supply of cotton is stopped, and the bagging from the reel *S* is fed around the bale, then pinned, and cut off. The roller *Q* is raised, and the bale taken out. A new core is put in, and the supply of cotton started again. During the covering and taking out of the bale—which takes about a minute—the gins have been running on, and the cotton accumulating in the hopper. This gives the reserve supply of cotton necessary to keep the bat even. The bale outside of the press has its

core pulled out, the bagging sewed up, and is then weighed and marked.

The speed of the rollers is figured to give the bat a weight of 2½ pounds per yard, and depends, of course, on the number of saws in the gins.

Description of the Machinery.

The lint flue which connects the gins to the condensers is made of sheet iron, and provided with gratings and dust boxes to take out as much dust, dirt, etc., as possible.

The condenser consists of a screen drum with open ends connected with the open air by dust flues, which conduct the air which has blown the cotton from the gins and the dust outside the gin building. The drum revolves as shown by the arrow, and thus constantly presents a clean surface to the blast of cotton and air, and acts as a carrier of the cotton to the two small doffer rollers. These wipe off the cotton from the drum. The drum and rollers are driven by one chain, as indicated by Fig. 180.

The cotton hopper, feeder, and bat former consists of an endless apron which is driven by the spiked picker roller, as is shown in the drawing.

The spiked picker is driven by a belt from the variable speed cones, shown in Figs. 181 and 182. The roller *K* is also driven from the spiked picker. A decrease of the speed effects all three alike: the cotton is brought up slower, carried over slower, and fed to the compression rollers slower. Thus, not only is the supply slowed up, but the cotton already in the bat-former is drawn out and thus thinned. If the bat is thin, the reverse is the case.

The regulating roller *G* has two sets of double-ended teeth which protrude from the roller at each side, and are so flexibly held that it is possible to make those on one end protrude more or less than those on the other end of the roller. The extent and place they will protrude is regulated by eccentrics on either end of the roller; thus it is possible to prevent the bat running thicker or thinner on one side than the other. The speed of this roller is constant.

The beater has two wings with spikes, which pass between those on the spiked drum, and two wings with leather flaps, which wipe the cotton off the spikes of the picker roller. The speed of this beater is also constant. The light flakes of cotton fly over the grating while the motes sift through.

The bat former compresses the loose lint and forms the thick bat. The large roller *K* is made of wire cloth of large mesh to allow any motes which might get over the grating above to fall out. This roller, by its varying speed, either pushes the cotton to or holds it away from the smaller compression rollers. The lower compression roller is covered with strips of rubber which aid

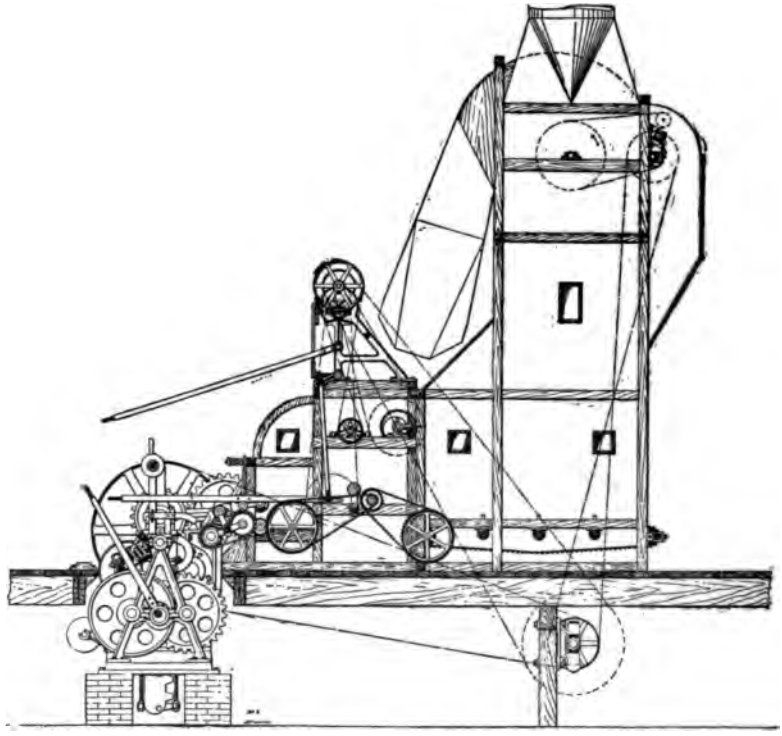

FIG. 181.

in wiping the cotton off the roller *K*. The rollers *L* and *M* are geared and driven together by four small gears. This method of driving allows them to spread very far apart without choking. They are driven from the press and go about 20 per cent. slower than the press rollers. They are held together by a helical spring. Their movement, to and from one another, moves the belt shifter on the speed cones, and causes the spiked picker to run faster or slower. If the bat gets too thin and the picker runs too fast, the cones are arranged to stop driving. This is shown

in Fig. 182. The bat is stopped by lowering the lower cone out of contact with the upper.

The press is the three-roller type. The two lower rollers are mounted in the side frames of the machine, and are fixed in rela-

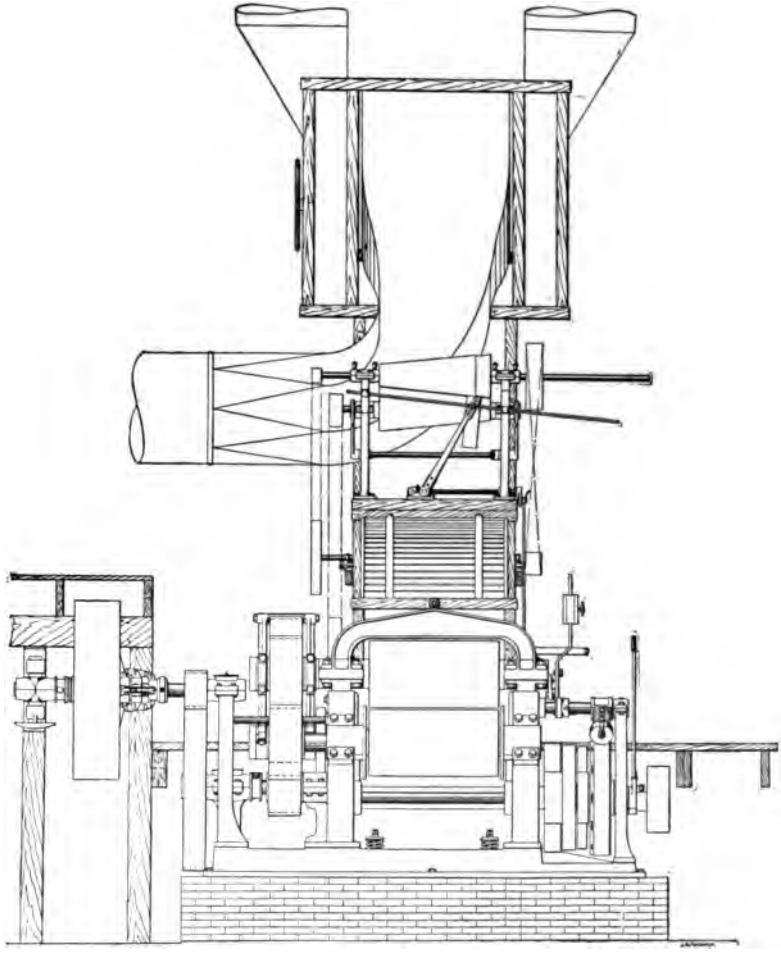

FIG. 182.

tion to one another. The top roller is mounted in a yoke which permits it to slide up and down in its guides. The two vertical sides of this yoke are racks, and their teeth mesh with smaller pinions. These pinions are keyed to a torsion shaft which is stiff enough to prevent either side of the yoke rising ahead of the

other. Opposite the pinions are rollers which take care of the side thrust caused by the teeth. These are shown in Fig. 183.

Keyed on the right end of the torsion shaft is a large gear; this gear, through three others, reduces the pressure 9.2 times until a friction brake is reached. This brake resists the movement of this train of wheels, and hence the raising of the top or pressure roller. The increase in diameter of the bale tends to push the roller up; the brake resists the upward motion. The tighter the brake is put on, the denser will be the bale.

I soon found out that the pressure must be increased as the bale increases in diameter, otherwise the core of the bales became packed to a density of 70 pounds per cubic foot and the cotton could not be unwound. A piece of cypress which I put in for a centre had its cross section reduced one-half, so some idea of how great the pressure must have been can be obtained. It was about this time that the mills did not care for such bales. The cotton appeared to creep upon itself, layer upon layer, so that, even if I started with a light pressure, the inner layers became very much thickened for the first five or six yards, and the cotton was buckled or crimped. So I could not start the pressure very light and then suddenly increase it, for the bale simply refused to stay round and became oval until the inner layers had been bunched together and the whole had attained the proper density. To overcome these objections I have devised the following means: A large double-tapered core is used which is greater in diameter at the ends than in the centre. At the ends are flanges which are loose, and serve to hold the ends of the bale and also act as the fulcrum of the lever which pulls out the core. The cones divide in the centre, as is shown in Fig. 184. This core is held about an inch off the two lower press rollers by flanges at the ends of these rollers. These flanges revolve with the rollers and cause the core to revolve a little faster than the rollers. The effect of this is to make the initial pressure on the cotton lap not more than the weight of the core itself, and to draw the lap around the core and thus prevent bunching at the start. This large core gives a firm centre on which to start the bale, and when it is withdrawn the hole it leaves is so large that the cotton caves in around the centre and thus softens up. The longer a bale stands, the softer it gets toward the centre. The weight of the top roller and its yoke is too great a pressure to exert on the core at first, so I have counterbalanced them by letting the yoke come down on helical springs.

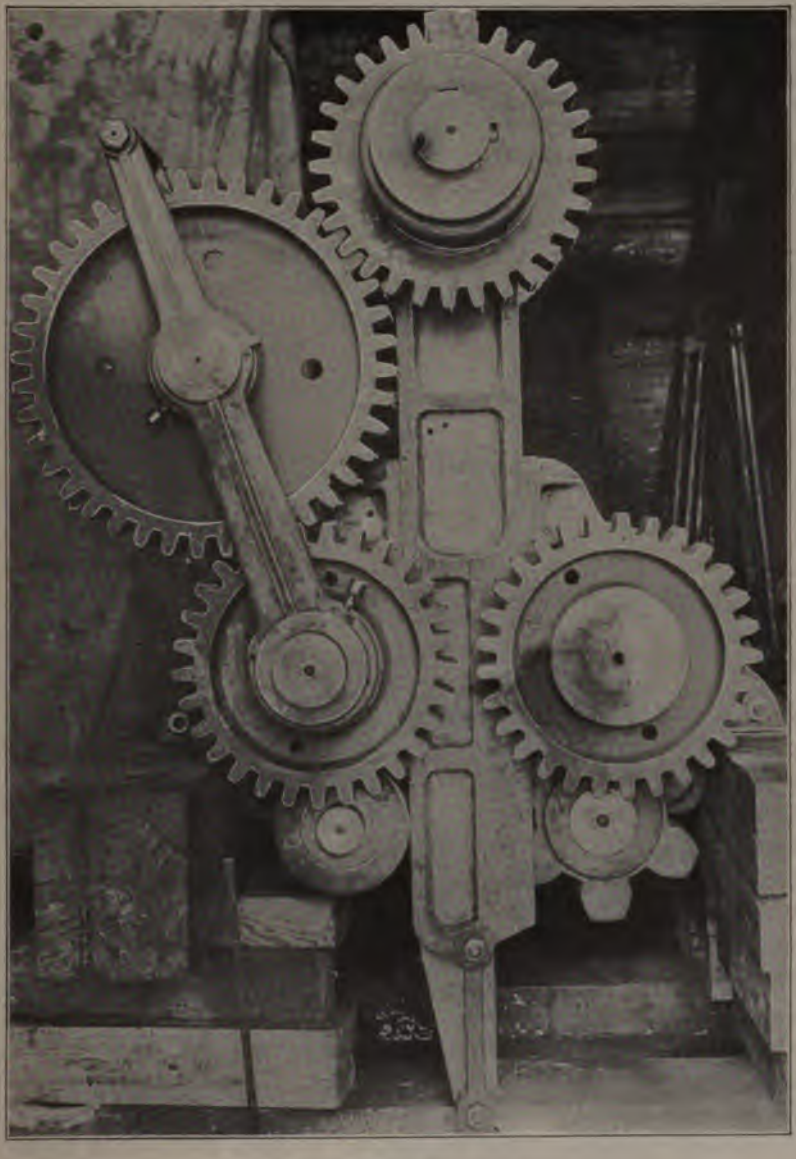

FIG. 183.—END VIEW OF PRESS.

These springs are shown in Fig. 180. By the time the bale has lifted the roller up about five inches, the full weight of the roller will be on the bale. After running a while under the weight of the roller and its yoke the brake begins to act, and its pressure continually increases until the bale is finished.

Figs. 185 and 186 show the brake on and off. The brake wheel is surrounded by a steel band lined with well-oiled leather, which allows the wheel to slip. On the pulling end of the band is a helical spring, which is gradually compressed as the strap is pulled around. This spring has a scale and pointer which indicate, just as a spring balance does, the amount of the pull. The slack end of the band is kept tight by a weighted lever. This

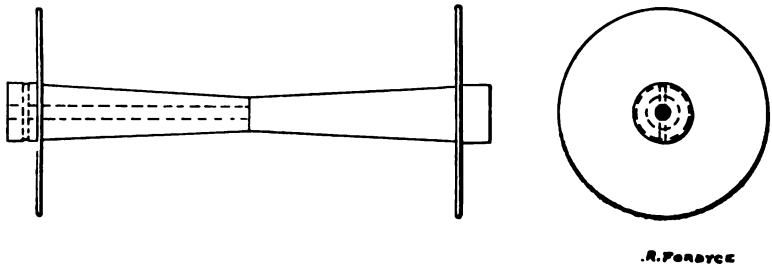

FIG. 184.

lever stands in a perpendicular position when the brake is off, and gradually drops to a horizontal position where it exerts its maximum pull. The point to which the slack end of the strap is fastened is at its greatest distance out from the centre when the lever is in the first position, and its least distance at the end, so that we have two varying factors—an increasing effect of the weight on the lever, and a decreasing length of lever arm through which the resistance acts. The combination of these is, of course, an infinite pull, but the spring on the pulling end lets us by this danger point, the weight rests on the floor, and we get only the maximum value of the pulling power of the spring. It is evident that this arrangement can never stick and break the machine, and that the maximum pull is always indicated.

The lever is tipped from its vertical position and held in its intermediate positions by a cam bolted to it, which strikes against a small roller which is bolted to the journal of the upper press roller. From Figs. 185 and 186 it is seen that it is not possible to put on the brake, except after the pressure roller has reached a certain

height, or after the bale has reached a predetermined diameter. This point can be changed at will by adjusting the cam. It is also evident that it is not possible for the brake to come on all at once, but it must exert a gradually increasing pressure; thus the pressure on the growing bale is as delicately balanced as it is possible for it to be made, and the additional precaution against hard

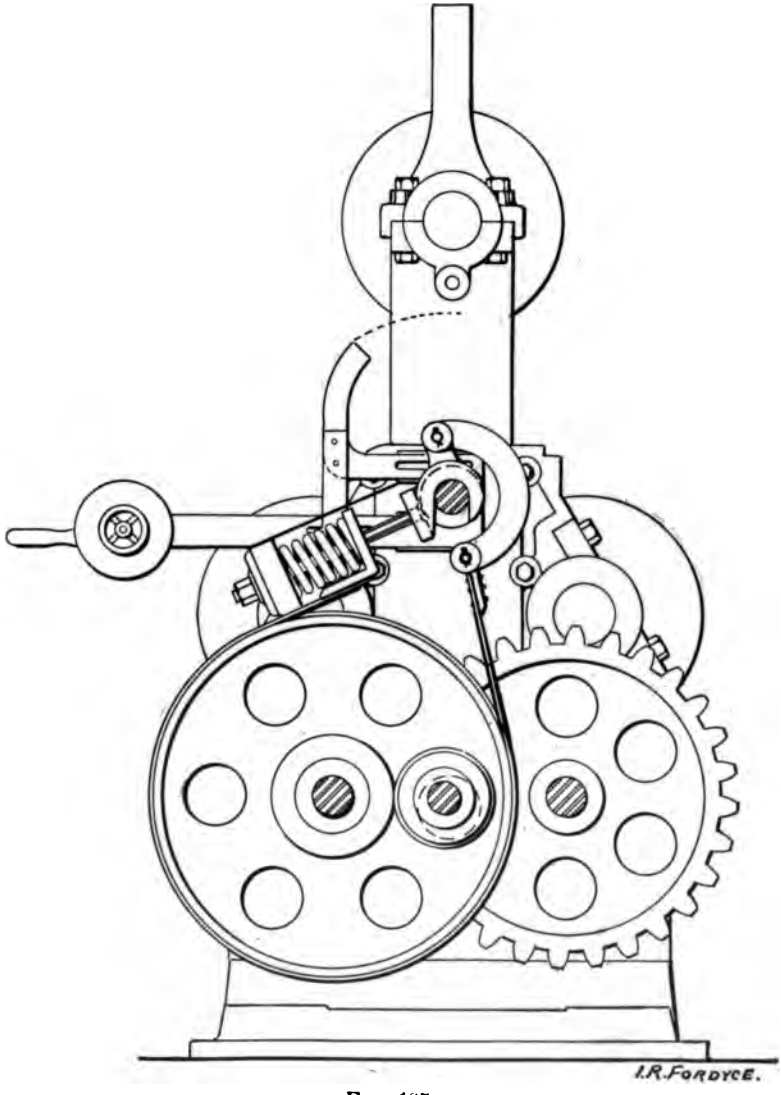

FIG. 185.

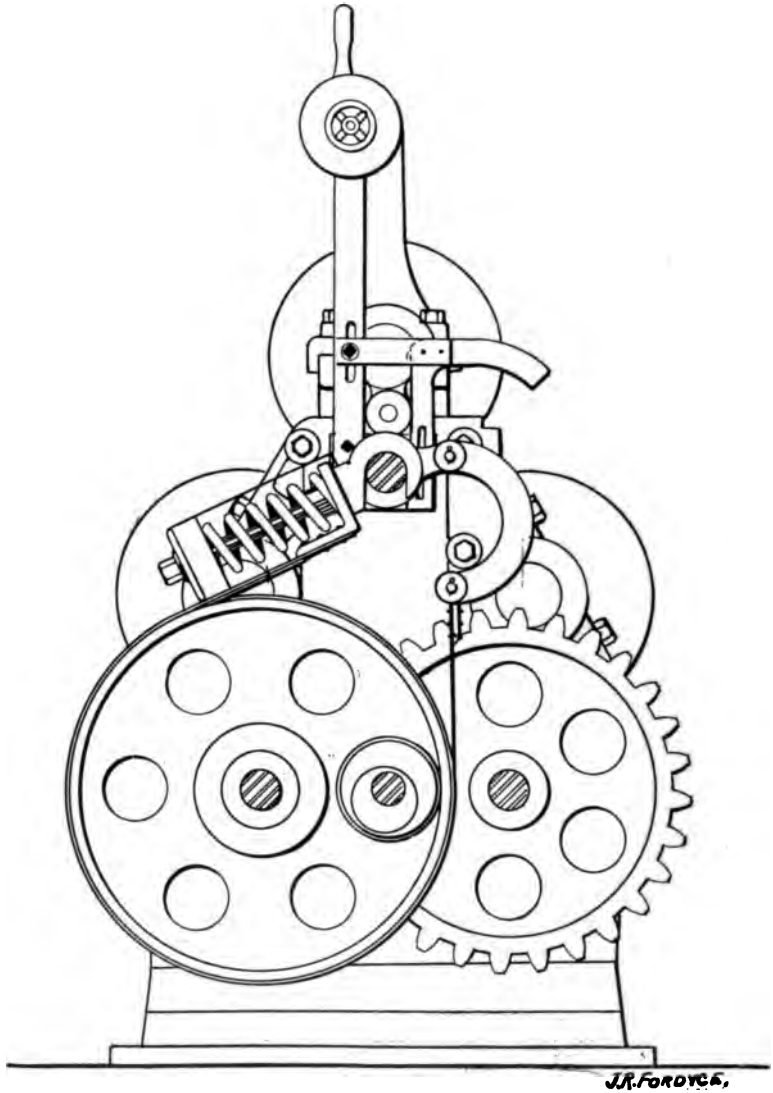

FIG. 186.

centres is taken by having the large core, on the withdrawal of which the cotton at the centre softens up. The speed of the bat former is made slower at first, so that the bat will be thinner and the consequent bunching up will only bring it to standard weight.

The top roller is raised and lowered by a paper friction wheel working in contact either with the inside of the rim of the brake

wheel or with its hub. This friction wheel is journalled in an eccentric box, and moved by the inclined lever shown in Fig. 181. The arrangement of the friction wheel and brake wheel is shown in Figs. 185 and 186.

The driving scheme for the rollers is shown in Fig. 186. The small pinion is mounted on the pulley shaft; and the press started

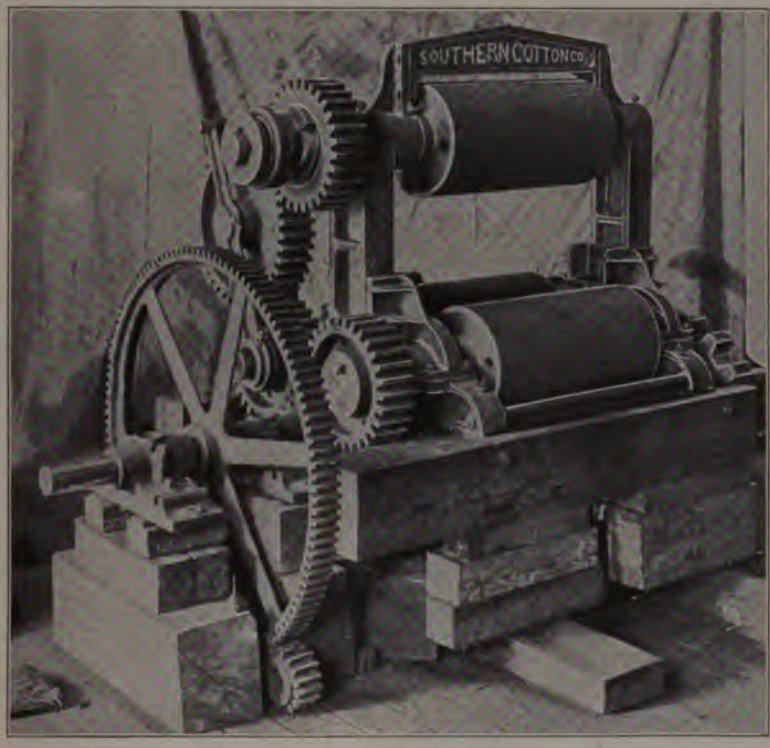

Fig. 187.—Press, showing Driving Gears.

and stopped by a friction clutch. The arrangement of the driving gear in the new model is shown in Fig. 182.

The speed of the rollers is determined by the fact that the best result in unwinding the bales is obtained when the weight of the bat of cotton averages about $2\frac{1}{2}$ pounds per yard. This weight of bat requires a less number of revolutions per bale than a thin bat would, and there is consequently less drawing or tightening of the layers upon one another. A thicker bat would be hard for the mills to work up.

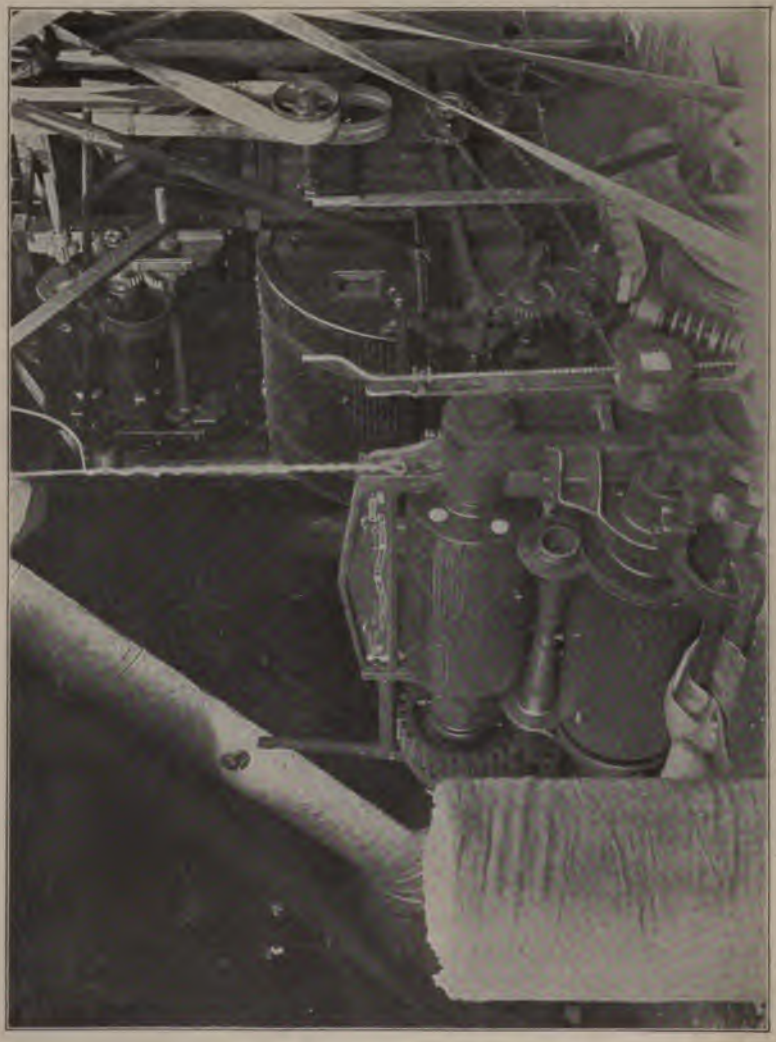

FIG. 188.—BALE AND PRESS.

Fig. 188 shows the press and its bale. The bales weigh about 250 pounds, and are 35 inches long and about 20 to 22 inches in diameter. This gives a density of about 35 pounds per cubic foot.

Bales are covered with a light-weight burlap or cotton duck. As there is no tendency for the bales to expand, hoops or wires are not needed. The bagging reel is carried on the front of the press as shown in Fig. 180.

From the above description it will be seen that the feeder and press is nothing but a larger and heavier form of the automatic feeder and breaker lapper of the mills.

A round bale is about ten times as dense as the round lap of the mill, and it usually has to be made in one-twentieth of the time of making a round lap.

In conclusion, the system from a mechanical standpoint is a success. From a commercial standpoint it is not fully established, but the prospects in that direction are very bright.

Already our company is erecting a goodly number of plants, and will be in a position to do a large amount of work this season.

There is a large field in the South for mechanical improvement, in cotton-handling machinery especially, and I hope soon to see the Society's membership extending in that direction.

No. 892.*

ON THE INFLUENCE OF TITANIUM ON THE PROPERTIES OF CAST-IRON AND STEEL.

BY AUGUSTE J. ROSSI, NEW YORK.

TITANIUM is found in nature almost as abundantly as iron itself. Titaniferous iron ores are met all over the world, and, in Sweden, Norway, Canada, in several States in the Union, and particularly in the Adirondacks district, they occur in "mountain masses," penetrating the igneous rocks, and constituting, in fact, the geological formation, the igneous rocks themselves being so impregnated and enriched with the iron-bearing mineral as to justify their being called an ore.†

It is not within the province of this paper to discuss the question of their smelting. It will suffice, for our purpose, to say that these titaniferous ores have been successfully smelted in blast furnaces for over twenty years in the Adirondacks (some fifty years ago), in England at Norton-on-Tyne for several years, and by ourselves more recently, and that we have obtained hundreds of tons of pig-iron, which have formed the basis of some of the experiments which we intend to describe.

Whatever may have been said of the economy of this smelting, one point on which all metallurgists seem to agree is the peculiar value possessed by the pig-iron which they yield. Though at the temperature available in the blast furnace the oxide of titanium is not reduced by carbon, owing to other combined influences, a certain amount of titanium finds its way into the metal, but always in very small proportions, rarely above 0.10 of 1 per cent. to 0.2 per cent. or 0.3 per cent., most generally a few hundredths, or even traces. So far as these ores have been smelted, and, we should say, in the conditions in which they have been

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* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† See "The Titaniferous Ores of the Adirondacks," U. S. Geol. S., No. XIX., Annual Report, 1897-98, Part III., by J. F. Kemp. "A Brief Review of Titaniferous Magnetites," *School of M. Quarterly*, vol. xxi., No. 1, 1899. *Ibidem.*

smelted, the pig-iron yielded is eminently a forge iron, an ideal open-hearth stock, low in silicon, quite free from phosphorus and sulphur (as these ores are, as a rule, generally free from phosphorus specially), and containing the carbon mostly in the combined state. The fracture is close grained, very much in appearance like steel, of which it has the grayish color rather than being white. This iron is very strong. Such expressions as "Wonderfully good," "All that can be desired," "Very tenacious pig," "Extra good iron, imparting to others, in mixture, properties of cold toughness" . . . will be met in technical publications here and abroad whenever this pig-iron is mentioned.

The "titanic pig" which we smelted from Adirondack ores contained but 0.11 to 0.13 silicon, and about 0.20 titanium; another, also smelted by us, contained silicon, 0.36; titanium, 0.07; combined carbon, 2.69 per cent.; graphitic, 0.24 per cent. As only a very small percentage (5 per cent. or thereabouts) of this pig was used in mixture with others in the tests described further, the results observed cannot very well be attributed to *the direct* influence of titanium, but rather to an indirect action, a remark which has been made very often by technical men.

It was as entering as a constituent for chilled castings that we had occasion to experiment with pig-iron of this class for a large manufacturing firm.

Test bars 1 inch by 1 inch by 13 inches long, tested 12 inches between supports, broke under a load at centre of 2,700 pounds; average of three bars.

The normal mixture used in this establishment, and which formed the basis of all mixtures, had an average transverse strength (three bars) of 3,390 pounds, bars of the same dimensions as above, and a chill of 1.062 inches on chill blocks $1\frac{1}{2}$ inches by $1\frac{1}{2}$ inches by 2 inches.

Experiments with Nickel alone.

The first experiments bore on the influence of additions of nickel to the normal mixture. We prepared for the purpose a ferro-nickel at 30 per cent. nickel. Cast bars 2 inches by 1 inch by 2 feet long of this ferro could be bent at right angles without breaking. Regular bars 1 inch by 1 inch by 12 inches between supports gave way under a load of 2,450 pounds at centre, but not by breaking or snapping asunder, as is the case

with cast-iron, but by bending gradually until the deflection at the centre reached much over 1 inch, when they generally split open in the length. Of this ferro-nickel we added to the normal mixture a sufficient quantity to obtain in the product increasing quantities of nickel of ½ per cent., ¾ per cent., 1 per cent., 2 per cent., 3 per cent., 4 per cent., 5 per cent., 6 per cent. At the same time as the bars, chilled blocks were cast in each case. The bars had the dimensions adopted for all others, viz.: 1 inch by 1 inch by 12 inches between bearings, 13 inches long.

The following diagram (Fig. 189) shows the results, taking the average breaking loads of three bars in each case as ordinates.

An inspection of this diagram shows that the transverse strength is decidedly increased (about 20 per cent.) by additions of small quantities of nickel up to 1 per cent.; after that this increase of strength diminishes to 5 per cent. for quantities of nickel reaching nearly up to 3 per cent., and then the strength remains stationary, or actually diminishes.

In fact, for these higher percentages of nickel, the bars bend to such an extent at the centre when a certain load is reached that the observations become difficult and uncertain.*

But the effect of additions of nickel on the chill is remarkable. From $1\frac{1}{8}$ inches with normal mixture, it drops to *nothing* with 6 per cent. nickel, and even the addition of 0.50 per cent. nickel is enough to cause it to drop considerably below the normal: 0.875 inch, as against 1.062 inches.

Experiments with Nickel and Titanic Pig.

By additions to the normal mixture of ¾ per cent. nickel and 5 per cent. titanic pig, the breaking load reached 3,750 pounds average, an increase of about 10 per cent. above the normal, and the chill 1.125 inches. In other words, an addition of 5 per cent. titanic pig brought back the chill to be fully equal to or greater than the original, while the strength secured corresponded to that obtained with 1 per cent. nickel, without addition of titanic pig.

By adding to the normal mixture ½ per cent. nickel and 10 per cent. titanic pig, the average breaking load reached 3,700 pounds, practically the same as above, while the depth of the chill reached 1.312 inches; in other words, the result of the addition

* Tensile-strength tests would certainly show much better figures for nickel.

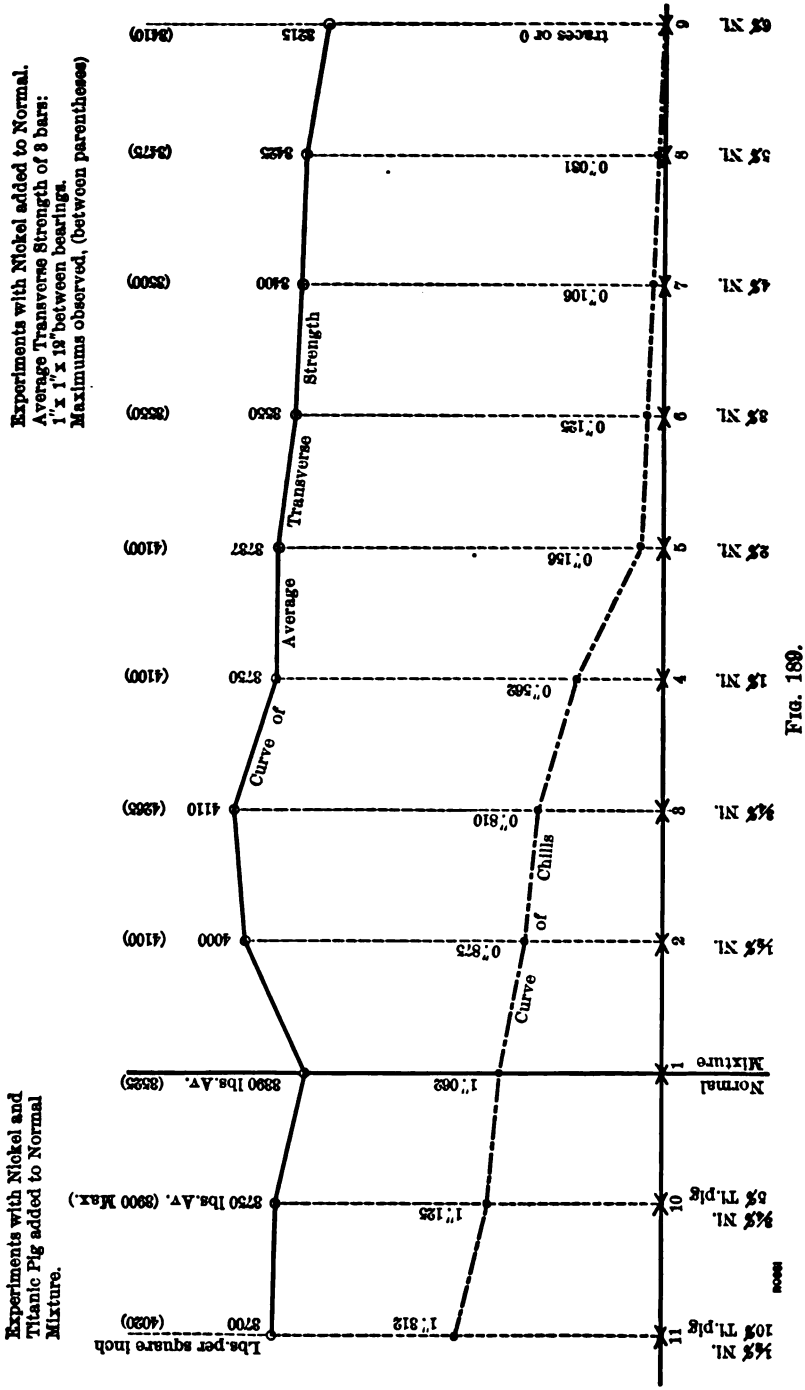

Experiments with Nickel added to Normal.
Average Transverse Strength of 8 bars:
1" x 1" x 12" between bearings.
Maximums observed, (between parentheses)
Curve of Average Transverse Strength
Curve of Chills
Experiments with Nickel and Titanic Pig added to Normal Mixture.
Normal Mixture
½% Ni.
1% Ni.
2% Ni.
3% Ni.
4% Ni.
5% Ni.
6% Ni.
½% Ni. 5% Ti.pig
½% Ni. 10% Ti.pig
Traces or 0
0".081
0".106
0".125
0".156
0".562
0".810
0".875
1".062
1".125
1".312
3215
3425
3400
3560
3787
3750
4110
4000
3890 lbs.Av.
3750 lbs.Av. (3900 Max.)
3700
(3610)
(3575)
(3500)
(3560)
(4100)
(4100)
(4265)
(4100)
(3825)
(4020)
Lbs.per square inch

Fig. 189.

of titanic pig to a greater extent (10 per cent.), with less nickel (0.50 per cent.), is to increase considerably the chill without impairing the strength. (Fig. 189.)

Experiments with Titanic Pig alone.

We experimented next with titanic pig alone, without additions of nickel. The diagram below (Fig. 190) summarizes the

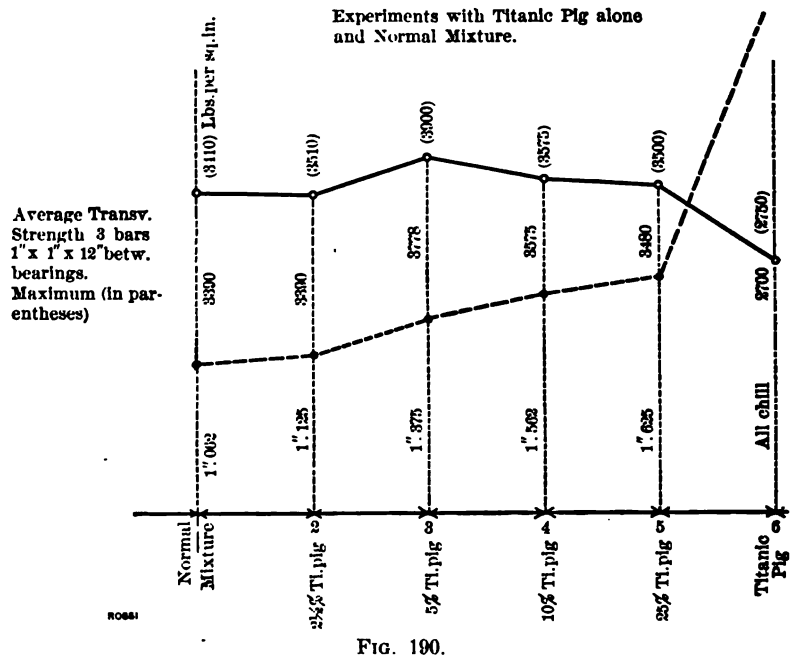


FIG. 190.

results obtained. A consideration of the latter shows that the addition of 2½ per cent. titanic pig increased the chill slightly, without any apparent action on the strength. An addition of 5 per cent. titanic pig increased the strength about 10 per cent. and the chill considerably more, about 30 per cent.; while an addition of 10 per cent. to 25 per cent. of titanic pig, without impairing the original strength—on the contrary, rather increasing it to an important extent—increased the chill to 50 per cent. or more above the normal.

The action of this titanic pig added to cast-iron is then shown by the diagrams to be an increase in the strength with an in-

creased chill, or a maintenance of the strength with a considerably greater chill, as much as 50 per cent. greater, or more. To all purposes, this addition is then preferable to that of nickel: on the score of cost, as to effect on the chill, and because, practically, the same strength can be secured without nickel addition as with it, within the limits of chill admissible. Results observed on bars were confirmed on castings made from these different mixtures.

The titanic pig containing, at the most, 0.2 titanium, the addition of 5 per cent. or even 10 per cent. of such pig could not introduce in the mixture (assuming no loss of any kind) more than 0.01 to 0.02 per cent. titanium as an outside figure, and to such small percentages, if any, it is rather difficult to attribute the results observed. By whatever cause they may have been secured, it was natural to study the action on the properties of cast-iron that the addition of an alloy could have containing a sufficient amount of titanium to introduce in a pig-iron larger quantities of the former metal than *mere traces*. Such alloys we have manufactured by the ton last summer, by different processes. Some of the alloys we have obtained contained but very small percentages of carbon—0.18 per cent. to 0.70 per cent., and from 10 per cent. to 75 per cent. titanium; others, on the contrary, contained carbon from 5 per cent. to 7 per cent., or even 8 per cent., and 10 per cent. to 12 per cent. titanium, occasionally as much as 15 per cent. to 20 per cent. This carbon was present almost invariably in the graphitic state, the combined carbon hardly reaching 0.20 per cent., generally 0.12 per cent. to 0.15 per cent., with S, 0.011 per cent.; P, 0.04 per cent. to 0.09 per cent.; silicon below or up to 1 per cent. to 1.50 per cent. It is this latter class of alloys which we have used to season pig-iron, with the results described below.

Experiments with Cast-Iron treated by Additions of Titanium Alloys.

We have added the alloy both in the crucible and in the pouring ladle; coarsely granulated, or even in lumps. Our experiments have been repeated by other parties in a large construction works and in car-wheel works, and our own results, as to extent of improvements observed, have been fully confirmed. We will not insist here on the different methods which we have tried in order to secure a better incorporation of the alloy. Adding the

alloy previously heated, and in as small fragments as practically admissible, secured, of course, the best results. We have not experimented yet by adding the alloy in the cupola; but in all our experiments, and in those made by others, we have found that an addition of 4 per cent, in some cases even less, of the 10 per cent. alloy was ample to secure a considerable improvement, both in the transverse and tensile strength of the metal.

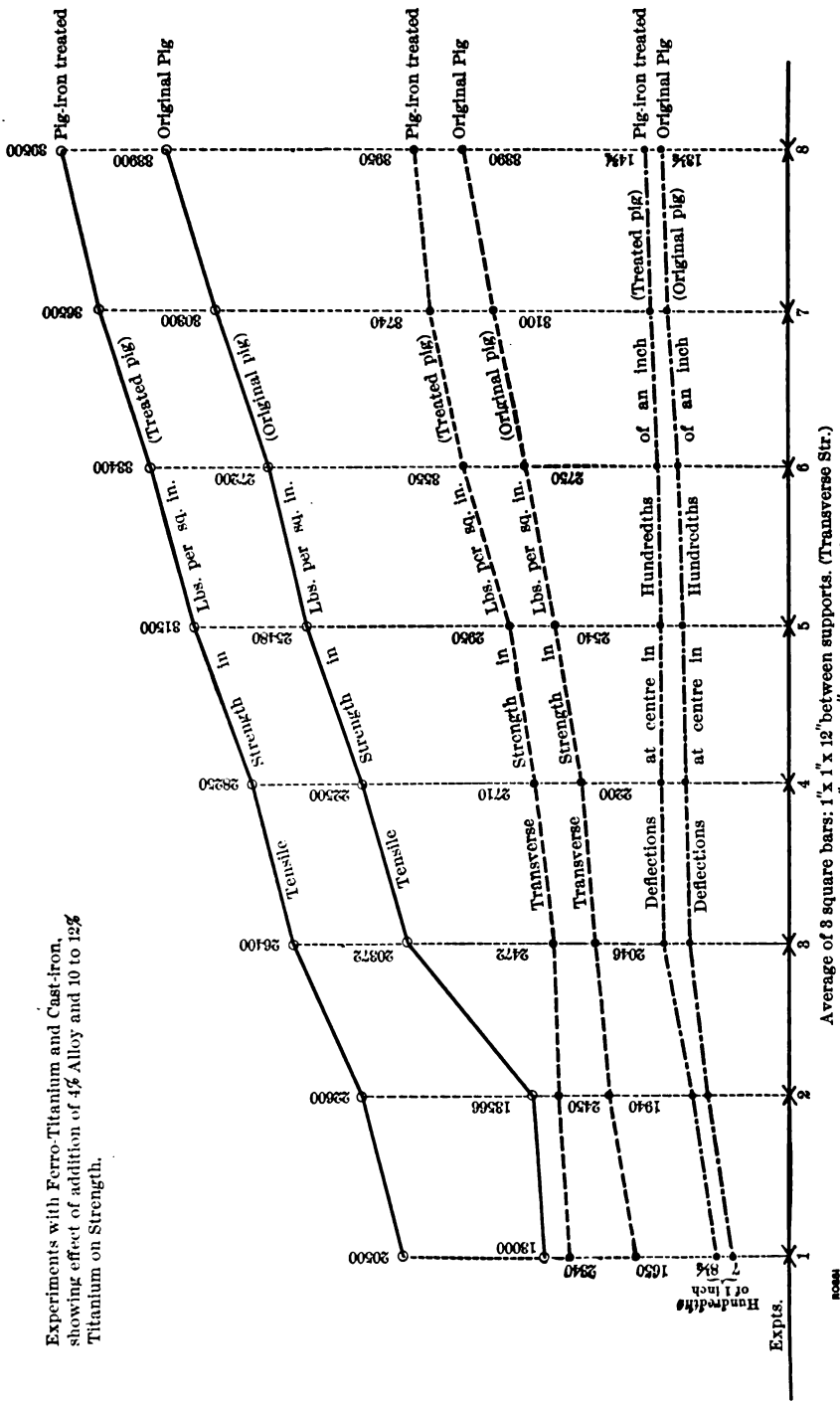
These 10 per cent. to 12 per cent. titanium alloys are much lighter than pig-iron, the specific gravity of *titanium* being less than 5, and for this reason they have the tendency to float on the surface of the metal treated. Enclosing the alloy in a cast-iron pipe, dropped hot in the bath of molten pig when operating on a ladle, would prove very successful.

Fig. 191 summarizes the results obtained by the addition of 4 per cent. of a 10 per cent. to 12 per cent. titanium alloy, containing carbon, to pig-iron of different quality.

It shows that by such an addition we have secured an increase of some 20 per cent. to 25 per cent. in the transverse strength, and from 30 per cent. to 50 per cent. in the tensile strength, of the metal, according to the nature of the pig-iron treated. This result can be obtained at an expense which does not materially increase the cost of the product, if we take in consideration the improvements secured, the small amount of alloy found sufficient to secure them, and the cost of the alloy, which we have been able to manufacture at such a low price as to admit of its industrial use. In many cases, indeed, the high requirements of specifications for superior products suppose a higher price for the cast-iron fulfilling them, and the addition of the alloy, by improving indifferent pigs and bringing them up to the mark, would prove even economical, the value of the alloy for the purpose once established without contest.

Analyses * made of the pig-iron, before and after treatment, showed practically the same amount of graphitic and combined carbon, *the same ratio of one to the other*, with no differences or but trifling ones as to silicon, sulphur, phosphorus, and manganese. The only element distinguishing them was titanium, present in the metal treated to the extent of 0.34 per cent. to 0.37 per cent., and 0.47 per cent. to 0.53 per cent. In these cases the percentages found are sufficient to have a *direct influence* on

* See table of Analyses.


Pig-iron treated
Original Pig
Pig-iron treated
Original Pig
Pig-iron treated
Original Pig
(Treated pig)
(Original pig)
(Treated pig)
(Original pig)
(Treated pig)
(Original pig)
Tensile Strength in Lbs. per sq. in.
Transverse Strength in Lbs. per sq. in.
Deflections at centre in Hundredths of an inch
Hundredths of an inch
Expts.
Average of 3 square bars: 1" x 1" x 12" between supports. (Transverse Str.)
Average of 3 round bars: ½" diam. x 18". (Tensile Strength)

Experiments with Ferro-Titanium and Cast-iron, showing effect of addition of 4% Alloy and 10 to 12% Titanium on Strength.

FIG. 191.

the quality of the metal, and the results show strongly in which direction.

The deflection curve (at centre of bars) corresponds quite well with the increased tensile strengths, and the curves representing this latter strength and the transverse strengths in the original metal and the metal treated are so nearly parallel (as soon as the pig-iron under experiment is not of an inferior quality) that the improvements observed seem to follow a law, and cannot be called casual.

We may remark here that the sizes adopted for the test bars—square bars 1 inch by 1 inch by 12 inches between supports for transverse strength; $\frac{3}{4}$ inch to 1 inch diameter by 18 inches long for tensile strength—may not be considered by many as the best size to adopt in such tests. Nor, we may say, were *the deflections* at centre measured with such an *accurate instrument* as would be strictly required, but all the experiments were made on the metal *before and after treatment*, with test pieces cast in the same conditions, tested in the same machine, measured with the same instrument, and they have at least the merit of being comparative.

We should add, also, that in all the tests made in crucibles our invariable practice was to melt the same amount (50 *pounds*) of the original pig-iron experimented with, casting from it 3 round bars and 3 square bars, and, when they were justified, chill test blocks.

The new charge consisted of 50 pounds of the same original pig-iron, to which was added the proper proportion of titanium alloy broken in sufficiently small fragments. From the well-melted mixture were cast the regular size test bars, as also chill blocks, when the condition of the experiment implied it, thus affording a good comparison of the properties of the metal before and after treatment.

When operating in the ladle (in car-wheel works, for instance) our practice has been to take from the pouring ladle, into a smaller ladle, the quantity of metal not treated necessary to cast the test pieces, and then cast the wheel from the original metal. The pouring ladle was then half filled with hot metal from the receiving ladle from the cupola, the intended amount of comminuted alloy dropped in, the charge in the pouring ladle completed, the mass stirred, and a sufficient quantity of treated metal taken for test pieces before casting the wheel.

The figure of 4 per cent. of alloy in weight of the pig metal is based on the weight of the wheel and gates as cast, and is then a maximum, as necessarily there always remains a certain variable amount of metal in the pouring ladle. Furthermore, if the alloy be used in too large pieces or is imperfectly stirred, a part of it is not thoroughly incorporated, and may remain floating on the metal. These circumstances may serve to explain certain discrepancies in the curves, which represent the results of practical tests and experiments.

Experiments with Steel.

Our experiments with steel have been limited, so far, to crucible steels. William Metcalf, in his "Manual for Steel Users," has called attention to the possible influence of gaseous elements present in steel and not generally determined, such as hydrogen, oxygen, and nitrogen. As to oxygen, it is practically and sufficiently removed in general by the addition of ferro-manganese; but it is not so with nitrogen, of which the influence is considered by Percy and many other metallurgists as decidedly weakening. Analyses made by Professor Langley, of crucible, open-hearth, and converter steel, have revealed the fact that the quantities of nitrogen found in these three classes of steel keep decreasing from the first to the last, and, as is well known, the qualities of strength of these different steels, even for the same composition with respect to silicon, sulphur, phosphorus, carbon, place the crucible steel at the head, and the converter steel the last. Mr. Metcalf has then suggested that the removal of nitrogen by some chemical affinity would be likely to improve the metals containing the most of it, that is, the open-hearth and the converter steel, and even the crucible steel to the extent of the nitrogen it contains also, and in this line of ideas he has suggested the use of titanium for the purpose.

The affinity of titanium for nitrogen is indeed so great that titanium will burn in nitrogen just as iron burns in oxygen. If such is the case, improvements in steel—even in crucible steel—could be secured by a very small addition of the alloy, and even if but a very small percentage of titanium were to be left in the treated metal. This, of course, would be independent of any specific action which titanium, by its presence in more important amount, could have on the properties of steel, as we have found it to be the case with cast-iron.

But experiments with crucible steel are difficult to carry on. It is necessary, when making them, that the metal obtained from a blank charge, without addition of alloy, should have the same composition as that obtained in a charge to which the alloy has been added. This is readily enough secured, as far as silicon, manganese, sulphur, and phosphorus may be concerned, but not so as regards the carbon; and differences in the percentages of this latter element may at once change a soft steel to a mild or hard steel, or *vice versa*—steels possessing entirely different properties, and not comparable. In making the tests described below we have used alloys practically free from carbon, made by a special process. They contain some 1 per cent. silicon, more or less; S, 0.011; P, 0.04 to 0.09 per cent., or even less, and aluminum occasionally; and of these alloys we have added from 2 to 5 per cent. to the steel, according to the percentage of titanium expected to be introduced and percentage of titanium in the alloy itself. The titanium alloys are so much more difficult to melt as they are higher in titanium, and, in general, we would not advise the use of alloys much above 15 per cent. titanium (at least for crucible steel).

We have chosen amongst the tests we have made such as are, we believe, the most characteristic, and for lack of direct terms of comparison with steels resulting from *the same charges* but not treated with the alloy, we offer steels of very nearly the same composition as to silicon, sulphur, phosphorus, and even aluminum, and containing the same amount of carbon. They are taken from Mr. R. A. Hadfield's paper on "Aluminum Steel":

	Carbon.	Titanium.	Alum.	Elastic Limit.	Ultimate Strength.	Contraction Area, p. c.	Elongation, p. c.
Hadfield	0.49	"	0.31	30,414	73,248	22.28	18.50
Titanium steel	0.479	"	0.30	35,000	81,250	38.80	24.40
Hadfield	0.65	"	0.18	32,211	58,912	4.40	3.50
Titanium steel	0.68	"	0.20	41,000	103,000	17.40	26.80
Hadfield	0.85	"	0.29	35,549	91,100	4.40	4.50
Titanium steel	0.854	"	0.29	76,500	141,500	14.60	8.40
Titanium steel	0.826	"	0.31	70,000	127,500	21.90	8.40
Titanium steel	1.227	0.53	0.00	59,250	— d	30.90	10.00
Titanium steel	2.165	1.07 } 1.10 }	.0	65,000	— d	10.50	8.75

All the steels treated with titanium contained about 0.10 per cent. titanium when not otherwise mentioned. The test bars

were 0.505 inch diameter, 2 inches between clutches, threaded as required by the regulations of the United States Government.

The alloy was added in small fragments, or even granulated, in the crucible with the charges, and in some cases dropped in that state into the molten steel; but it would have been much preferable to enclose it in an iron pipe, heat the latter, and drop it into the molten steel or add it cold with the charge, in the pipe, as it is practised with other ferros. A great deal of the alloy, and consequently of the titanium, was lost by oxidation as it floated on the surface of the molten bath of steel, the alloy being considerably lighter than steel, especially when high in titanium, as we have had occasion to remark.

As far as these experiments did go, and we made some 1,200 or 1,500 pounds of ingots, they seem to show a remarkable elongation and reduction of area; in high or very high carbon steel, titanium appears to act somewhat like nickel in this respect. Chisels, crowbars, cutting tools were made from such steel, and they were declared to be excellent. The chisels kept their temper well, being tempered hard, but did not waste on the head under the blow of the hammer—they "mushroomed," as the workmen expressed it. Our experiments in this line, however, are far from being complete, and others are in progress, or will be soon, in open hearth and in the converter. It is possible that for the two latter applications, alloys higher in titanium than 10 to 12 per cent., or even 15 per cent., proved very admissible.

The alloys high in carbon could certainly be used instead of those practically free from it—even for crucible steels. A 10 per cent. alloy, containing, say, 7 per cent. C, added to the extent of, say, 4 pounds to 100 pounds of steel, would introduce in the steel only 0.28 carbon. That is much less than the steel treated is intended to contain, let it be a semi-hard and specially a tool steel, in which case the carbon expected is to reach 0.50 to 0.90 and more, or thereabouts, and it would be only a matter of adjusting the carbon-bearing materials of the charges to take care of the carbon supplied by the alloy.

Conclusion.

In conclusion we believe ourselves justified in saying that, as far as cast-iron is concerned, the improvements observed by additions of small percentages of titanium alloys cannot be con-

tested, corroborated as our results have been by experiments made by others and independently of us. They bear both on the transverse and tensile strength, which are increased, the former some 20 to 25 per cent., the latter 30 per cent. or more, according to quality of the original pig-iron.

As to steels, limited as our experiments have been, and limited to crucible steel as they were, the influence of titanium seems to have been very much in the same direction as for cast-iron—an increase in the ductility of the metal, as shown by the increased contraction of area and elongation and of the elastic limit in high-carbon steels.

We have purposely avoided in all the above any mention of the manufacture of the alloys, desiring to examine particularly in this paper the influence of titanium on the properties of iron. A few succinct details, however, on the methods which we have followed may prove of interest, as some bear a direct relation to the production of alloys of titanium with *other metals than iron.*

Any titaniferous iron ore, sufficiently free from injurious elements and high enough in titanium, will prove suitable for a first material. The powdered ore is intimately mixed with powdered charcoal, and the mixture charged in the graphite cavity of a block forming the electric furnace, or crucible. Its construction is very much like that described by Siemens some twenty years ago. This graphite block and its contents form the cathode. A set of carbons, bunched together and forming the anode, penetrates in the central cavity of the furnace, leaving between the carbons and the sides of the crucible a space sufficient for the introduction of the charge. The lowering or raising of the carbon anode, by means of any appropriate mechanical device, allows the arc to start through the mass, the heat generated being sufficient (probably some 2,800 degrees C., more or less) to cause the reduction of titanic oxide by carbon, a reduction which requires this intense heat, the iron oxides of the ore being, of course, readily reduced in these conditions. The two metals melt, and alloy and the earthy materials of the ore float as slag on the surface of the metallic bath. With the ores which we have used, the amount of this slag was *very limited.* The proportion of *titanium* to the *iron* in the ores treated necessarily fixes and limits the percentage of the first metal in the product. If this is higher than is desired, a certain amount of scrap-iron can be added to the mixture of ore and carbon and charged in

the furnace first, in order to obtain any other percentage desired, but there is a *maximum* possible depending upon the composition of the ores themselves.

We have thus obtained alloys containing from 5 to 7 per cent. of carbon (more or less), mostly, as we have said, in the graphitic state, and titanium in variable proportions from about 10 per cent. to 25 per cent., or more.

For certain purposes the presence of carbon may prove objectionable, and we have made alloys containing but 0.18 to 0.70 of carbon, operating in the same furnace, by substituting aluminum for carbon as a reducer of the metallic oxides. This property of aluminum to reduce nearly all metallic oxides has been known for the last fifty years or more as a laboratory experiment. If aluminum in impalpable powder be mixed with finely powdered oxides and the temperature raised in one point of the mass by means of a primer of magnesium, for instance, the reaction will proceed by contiguity of mass without the intervention of any external heat. A temperature estimated by some to be as high as 3,000 degrees C. can thus be secured, and it has formed the basis of a special industry, the "aluminothermics," as it has been called in Europe. In such case the aluminum powder is mixed with oxides yielding their oxygen readily, the reduction of the oxides being but a means of securing the heat, and not the purpose of the operation. Dr. Goldschmidt, to whom the industrial realization of a well-known principle is due, has been able, with proper devices, to generate heat *in loco* sufficient to solder iron and steel castings, and to melt metals difficult to melt otherwise. Applied to *the reduction of metallic oxides* in order to obtain alloys, simple as the method appears, it becomes very expensive, as the aluminum in powder costs six or seven times as much as aluminum in ingot.

We have found that, instead of using aluminum in fine *powder*, all the reactions of aluminum in this state can be secured by *a bath of aluminum* brought to a proper temperature, such as is conveniently secured in an electric furnace, for instance.

If, then, in our furnace we charge aluminum, scrap or ingot, melt it, and charge the titaniferous iron ores, in the bath the latter are readily reduced as they were before by carbon, and the heat generated by the oxidation of aluminum allows us to moderate considerably the current applied at a certain stage of

the operation. We have thus obtained alloys practically free from carbon, while the aluminum, oxidized to alumina, formed with the gangs of the ores an aluminate which floated on and separated cleanly from the metallic molten mass of the alloy. This aluminate is harder than natural corundum, and can be used as an abrasive material, or it can be used as a source of alumina, the basis of the manufacture of aluminum. Alloys can be obtained in this manner at a much cheaper cost than with powdered aluminum, in the proportion of the cost of this metal in the two states, as the cost of the "*external heat* supplied" in this case is but an insignificant part of the total expense incurred. But we have used another process of manufacture, of which the economy is considerably greater.

From a titanic iron ore containing, for illustration's sake, 20 per cent. titanic acid (12 per cent. titanium) and 70 per cent. oxide of iron (say 50 per cent. iron), it is clear that, *theoretically*, we cannot obtain more than $\frac{12}{62} = 19.35$ *per cent. titanium* in the alloy, let the reducer be carbon or aluminum and the latter in powder or in ingots, and let the heat be supplied externally, or directly and internally by the oxidation of aluminum; but furthermore, the quantity of aluminum to be added to the ore (leaving aside all questions of heat) must be such, in order to secure the reduction of the oxide, as to satisfy the chemical equation: $Fe_2O_3 + Al_2 = Al_2O_3 + Fe_2$; that is, for every pound of oxide of iron (or say $\frac{7}{10}$ of a pound of iron reduced) we *must* add, in round numbers, $\frac{1}{3}$ pound of aluminum. Our only alternative would be, then, instead of titaniferous IRON ores, which are not any more expensive than ordinary iron ores, to use *pure titanic acid or oxide* (TiO_2) *rutile*, which occurs in nature not *very abundantly*, and costs even when but comparatively free from iron, something like $450 to $350 a ton.

Our method consists, starting from the above titaniferous iron ore taken as an example, to mix it with only such quantity of charcoal as is necessary to reduce the oxides of iron, but *not* the titanic oxide, and submit the mixture to a current of a very low intensity, not sufficient to reduce the titanic oxide, realizing in our furnace a temperature but slightly higher than that secured in a blast furnace, having previously added to the mixture of carbon and ore a quantity of limestone, or preferably *lime*, capable of forming, with the titanic acid of the ore, a regular titanate slag.

We have thus obtained, as a by-product, all the iron of the ore in the form of a charcoal titanic pig possessing all the valuable properties of such pig-iron, and in which are found some silicon, sulphur, and phosphorus from the ores and a *slag* or *concentrate of titanic acid*, practically free from iron and containing practically all the titanic acid of the *ores*. Treated by carbon or aluminum, this concentrate theoretically would yield metallic TITANIUM without iron, and with proper mixtures with scrap-iron, titanium alloys as high as might be desired. We have thus indirectly obtained from a titaniferous ore containing 12 per cent. of titanium, an alloy containing 75 per cent. of titanium.

This concentrate not containing any *oxide of iron* practically, no aluminum needs be added on this score, and as this concentrate costs us nothing, all expenses to obtain it being covered and above by the value of the titanic pig obtained in the intermediary operation, the economy realized is considerable; and, in fact, alloys free from carbon, obtained by using aluminum as a reducer, by this method are but very little more expensive than those obtained from carbon itself.

But this concentrate has another application. Being practically free from iron, it can form the basis of the manufacture of alloys other than ferros. By using this concentrate as a basis and source of titanium, and charging *copper scrap* in a furnace instead of the ore, with the proper proportion of aluminum to reduce the titanic oxide of the concentrate, we have obtained alloys of titanium and copper, cupro-titanium, containing from 8 to 15 per cent. titanium.

Added to manganese bronze in a large construction establishment in the proportion of 4 pounds of the alloy (10 per cent. Ti) to 100 pounds bronze, the results were so satisfactory as to justify the protracted tests contemplated. The following results were observed on bars 0.795 diameter, area $\frac{1}{2}$ square inch, length 2 inches between clutches: Elastic limit, 25,200 pounds per square inch; tensile strength, 63,080 pounds; reduction area, 41.56 per cent; elongation, 45 per cent.

NOTE.—For more complete details on the manufacture of the alloys, furnaces used, reactions taking place, analyses of products, we refer to Vol. IX. of *Mineral Industry*, article on "Titanium and its Alloys," from which article some of the above has been résumé.

This volume is in press.

ANALYSES.

Pig-Irons Tested (Diagram *C*).

No. 2—Analysis by Dr. Ch. F. McKenna, on bars tested.

	Before Treatment.	After Treatment.
Total Carbon	3.856	3.668
Combined Carbon	0.758	0.709
Graphitic Carbon	3.098	2.954
Ratio of $\frac{\text{Combined C}}{\text{Graphitic C}}$	24.4 per cent.	24 per cent.
Phosphorus	0.88	0.85
Sulphur	0.05	0.05
Silicon	1.87	1.83
Titanium	0	0.37

No. 3—Analysis as given to us by the parties who made the test.

Total Carbon	3.59
Graphitic Carbon	2.98
Combined Carbon	0.60
Manganese	0.78
Phosphorus	0.52
Sulphur	0.052
Silicon	Not given.

No. 8—Analysis by parties who made the tests.

Total Carbon	3.50	3.50
Graphitic Carbon	2.32	2.13
Combined Carbon	1.18	1.37
Manganese	0.796	0.714
Sulphur	0.138	0.104
Phosphorus	0.34	0.367
Silicon	0.78	0.83

Titanic Pig-Irons.

	Smelted from Titaniferous Iron Ores in Blast Furnace, by A. J. Rossi.	Obtained as a "By-product" with the "Concentrate," in our Manufacture of Alloys.
Total Carbon	3.345	3.676
Combined Carbon	3.090	3.500
Graphitic Carbon	0.255	0.176
Silicon	0.36	0.210
Phosphorus	Traces	0.052
Titanium	None to 0.07	0.034
Manganese	0.25	Not determined.
Sulphur	0.022	0.021

Explanations of Diagram.

No. 1—Common foundry pig-iron used for ordinary castings. Experiment made in crucible.

No. 2—Foundry-iron No. 2x, used in a foundry at Jersey City for machinery castings. Experiment made in crucible.

No. 3—This experiment was made at the testing department of a large construction firm in Philadelphia, independently. Cast-iron such as they use in their shops. Ladle or crucible.

No. 4—This experiment was made in car-wheel works in our presence, but independently *in the ladle*. Wheels were cast from the mixture, treated with alloy, and without additions of alloy.

No. 5—Very good foundry-iron, from Paterson, N. J. Experiment made in *crucible*.

No. 6—Experiment made in crucible.

No. 7—Experiments in iron works. Made in *the ladle*, independently. Wheel cast from mixture treated.

No. 8—Experiment made in crucible.

No. 893.*

PORTABLE VERSUS STATIONARY MACHINE TOOLS.†

BY JOHN RIDDELL, SCHENECTADY, N. Y.
(Member of the Society.)

PORTABLE machine tools are to-day made and used for a great many different purposes undreamed of fifteen or twenty years ago. There are several reasons for this. One is that since electricity has come into general use, the driving of portable tools has become very much less of a problem than before; and another reason is that compressed air is more generally used, as may be seen by the great number of pneumatic drills and chippers in use.

In a discussion of the larger portable tools, those which really do the work of large stationary tools, a very good example is presented in the drilling of large pieces by a stationary radial drill, as compared with the same operation on a portable drill. The photograph in Fig. 192 shows a large magnet frame suspended from a travelling crane while having the pole-piece bolt holes drilled by a stationary radial drill. This operation requires not only the services of a crane and a man to operate it, but also at least two floor men and one drill-press hand. It is also a rather dangerous operation, since, if the blocking is not carefully done, the piece is very apt to slip and cause trouble. Fig. 193 shows the same operation as effected by a portable drill, and it will be noticed that there are two other machines at work on the piece at the same time. Two men can run these three machines and have time to spare. It will hardly require any further argument to show which is the better way.

Figs. 194 and 195 show a similar piece having the feet planed.

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*Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† For further discussions on this topic consult *Transactions* as follows:
No. 806, vol. XX., p. 435: "Topical Discussions." Also references to electric transmissions in shop, in paper No. 908.

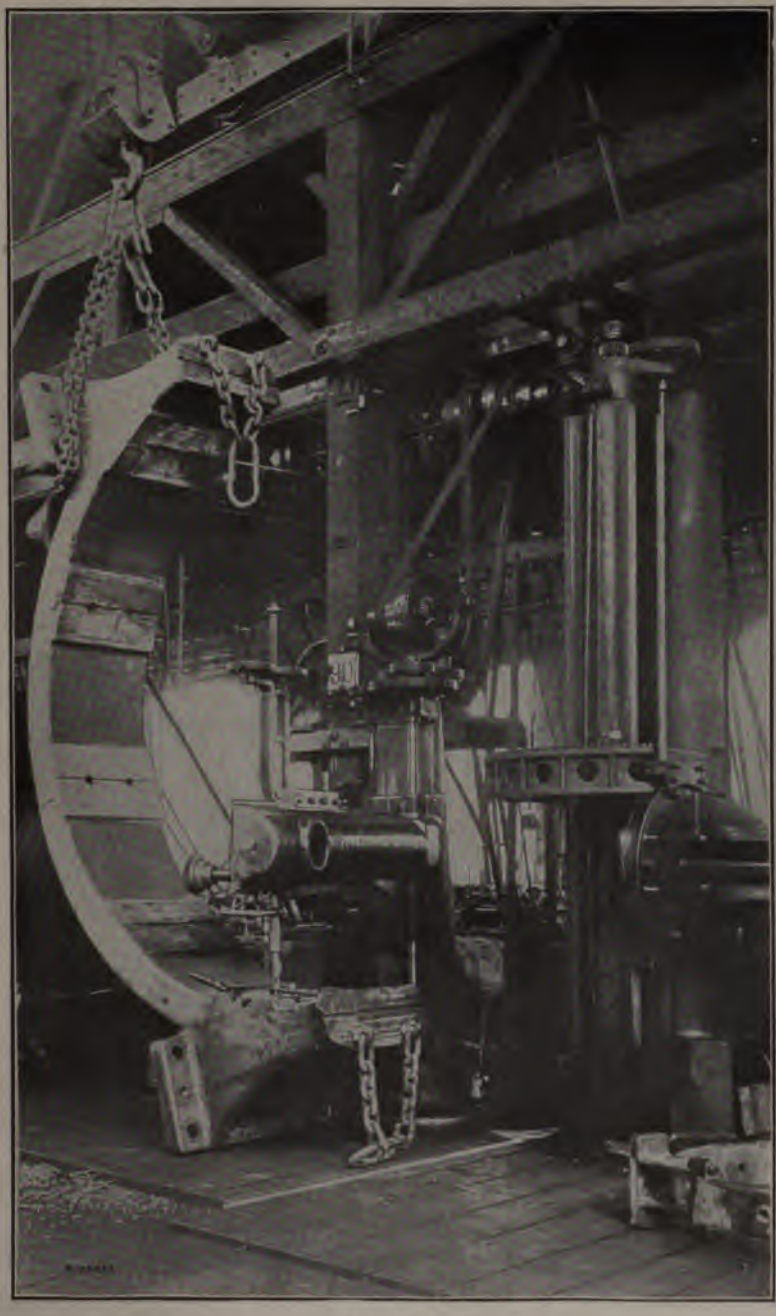

FIG. 192.

Fig. 194 shows it on a reciprocating planer, while in Fig. 195 it is on a floor plate having the same work done by a portable shaping machine. This operation is generally done by the portable slotters which are shown in Fig. 193, when two slotters can work on the same piece at once.

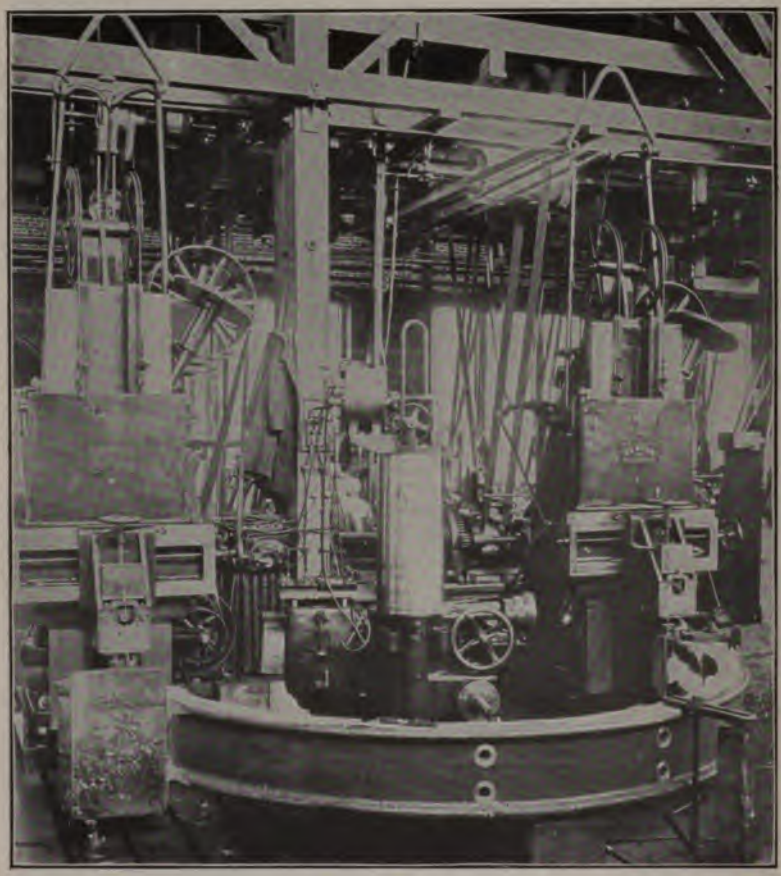

FIG. 193.

Fig. 196 shows two of these machines at work on the joint of one of these large magnet frames.

It may be of interest to know something about the drive shown on these slotters. The motors are 8 horse-power, 1,500 revolutions per minute, 250 volts. Each end of the armature shaft is provided with a pinion, the right-hand pinion engaging directly with the large spur gear as shown. The other pinion

meshes into an intermediate gear, which, in turn, engages with the gear at the left-hand side. To each of these gears is attached an electro-magnet which is in the form of a disc. Between the discs is a long sleeve sliding on a splined shaft, on each end of which is a large shoulder which fixes the distance between the two magnetic clutches. On each end of the sleeve referred to is another disc. These discs, however, are perfectly

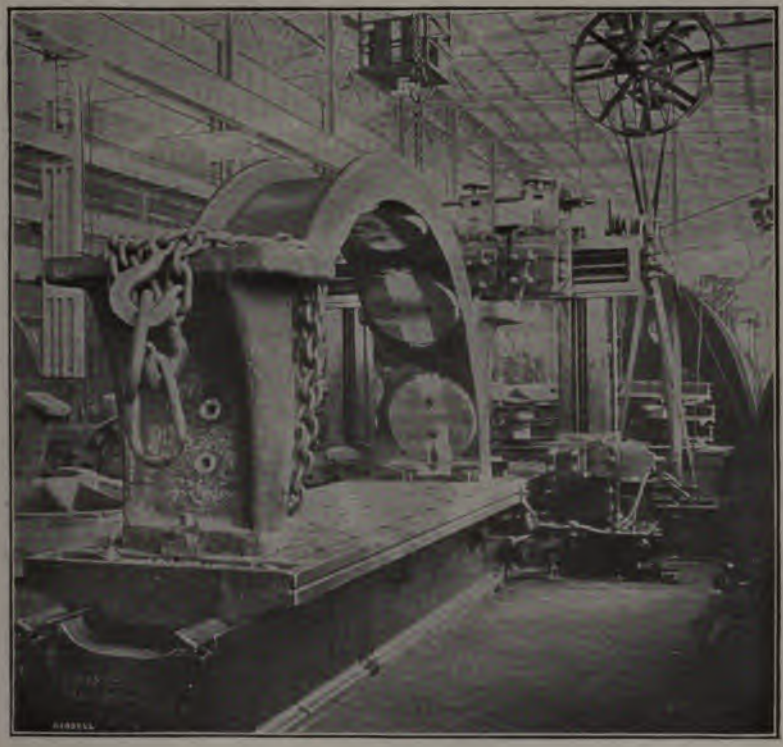

Fig. 194.

plain. Current controlled by a switch on the opposite side of the slotter is supplied to the clutches through collector rings, the switch being operated by dogs on the sliding head in the same manner as belt shippers are operated by planer dogs.

The clutches referred to have been in successful operation for about two years on a 120-inch Bement planer.

Figs. 197 and 198 show a portable boring bar for large spiders or similar pieces. I do not happen to have a photograph

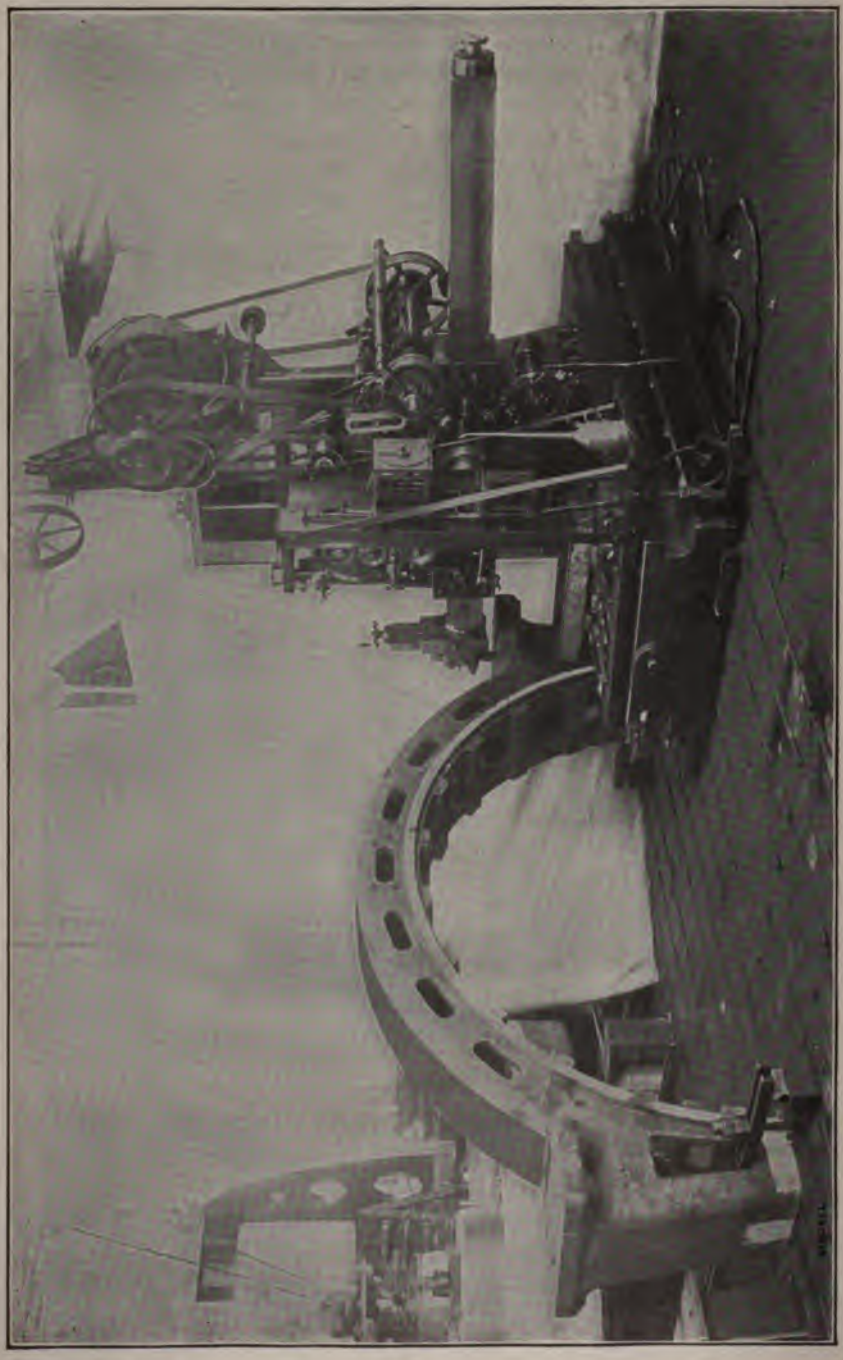

FIG. 195.

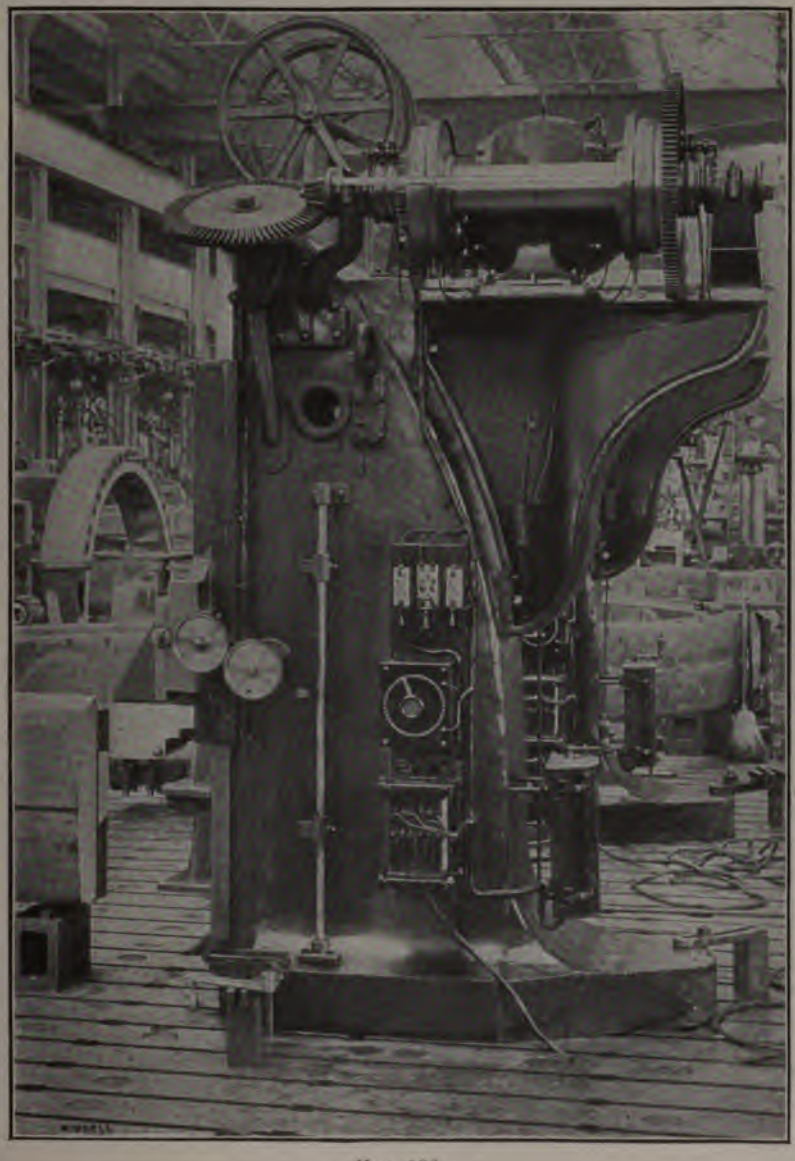

Fig. 196.

FIG. 197.

FIG. 198.

of this operation on a large boring mill, but you are all more or less familiar with the operation and can readily imagine what it would look like. The largest mill at the works where this bar is used is a 16-25 foot extension mill, and to bore one of the spiders referred to it would be necessary to extend the mill to 25 feet and use the extension arm which fits on the cross rail.

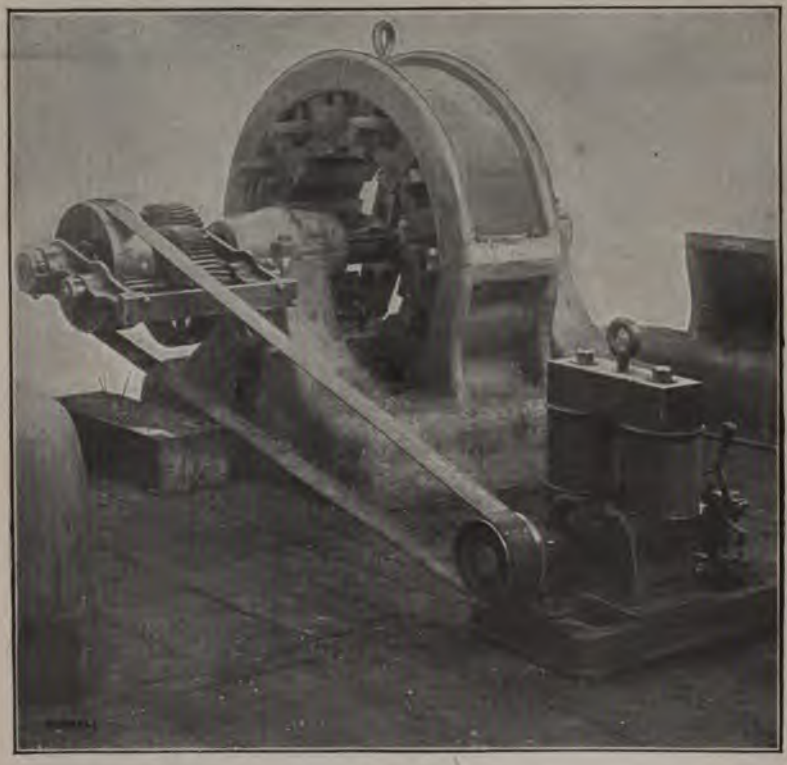

FIG. 199.

This arm projects five or six feet out from the cross rail, which in itself is a rather weak contrivance. A boring bar is provided to slide in the extreme end of this arm for boring. This whole arrangement is necessarily very weak and heavy cuts cannot be taken with it, and a great deal of time is consumed in doing a comparatively small job. I have known some cases where from forty to fifty hours were required to bore one of these spiders. With the portable bar the same work has been done in a much more satisfactory manner and required only from

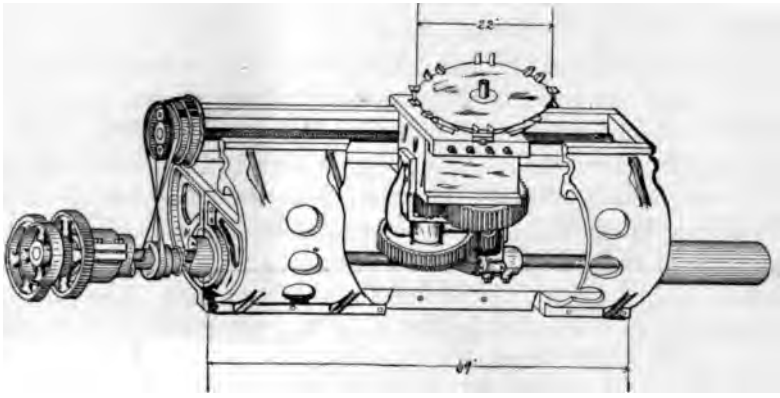

FIG. 200.

fifteen to twenty hours. This bar also has the advantage of being used in any convenient part of the shop, and the use of it leaves the larger and more expensive tool free for other work.

Fig. 199 is another illustration of saving a large stationary

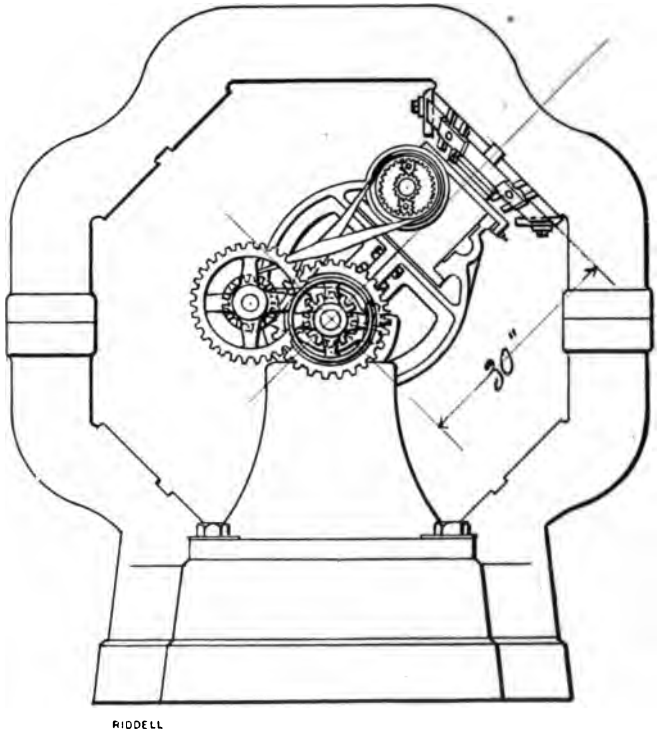

FIG. 201.

boring mill by the use of a portable bar. This is an old and well-known type of bar and will need no further description.

Fig. 200 has gone out of use and is only shown here as a matter of curiosity and comparison between portable and stationary machine tools. There was a time in the history of the company which built the dynamo (an outline of which is shown in Fig. 201) when there were at least four factories planing the pole faces and joints of these dynamos. The time required to plane one set of pole pieces was about forty hours. The planing machines used were 96 inches wide and represented an investment of about $8,000 each.

The time required by the milling machine to do the same work was about twelve hours and the investment was about $1,000. It was found necessary to build three of these machines to keep up with the orders for this particular type of dynamos. Allowing that one of the milling machines would do the work of three planers, it will readily be seen that an investment of about $72,000 would have to be made, to say nothing of the floor space required. The milling machine could do its work in any place where the dynamo frame could be set up.

No. 894.*

TEST OF AN HYDRAULIC AIR COMPRESSOR.

BY WILLIAM O. WEBBER, BOSTON, MASS.

(Member of the Society.)

SOME tests made September 10, 1899, of an hydraulic air compressor operating at the plant of the Dominion Cotton Mills Company, Limited, at Magog, P. Q., Canada, gave the results which are recorded in the following paper.

These tests were made on an hydraulic air compressor known as the Taylor compressor.

This compressor embodies the principles of the old trompe used in connection with the Catalan forges some centuries ago, modified according to principles which were first described by Mr. J. P. Frizell, in an article in the *Journal of the Franklin Institute*, September, 1880, which was further improved by Charles H. Taylor, of Montreal, and patented by him July 23, 1895.

It consists principally of a down-flow passage having an enlarged chamber at the bottom and an enlarged tank at the top (Fig. 202). A series of small air pipes project into the mouth of the water inlet and the large chamber at the upper end of the vertically descending passage, so as to cause a number of small jets of air to be entrained by the water.

At the lower end of the apparatus, deflector plates, in connection with a gradually enlarging section of the lower end of the down-flow pipe, are used to decrease the velocity of the air and water, and cause a partial separation to take place.

The deflector plates change the direction of the flow of the water and are intended to facilitate the escape of the air, the water then passing out at the bottom of the enlarged chamber into an ascending shaft, maintaining upon the air a pressure due to the height of the water in the uptake, the compressed air being

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

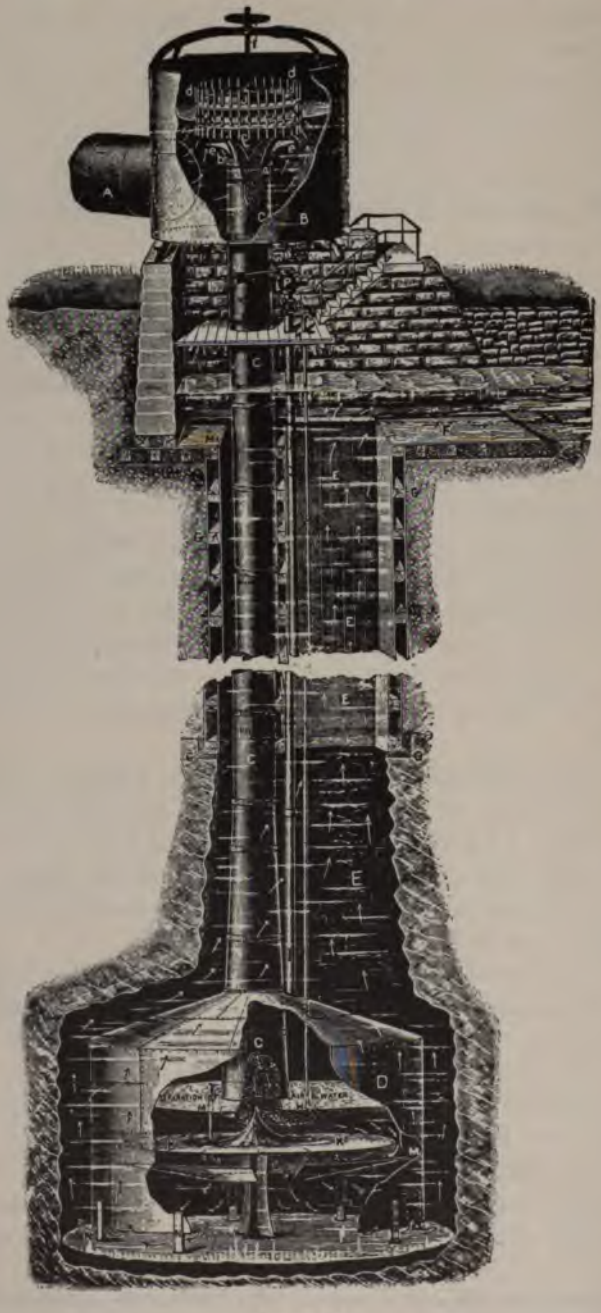

FIG. 202.

led on from the top of the enlarged chamber by means of a pipe.

The general dimensions of the compressor plant are:

Supply penstock	60 in. diam.
Supply tank at top	8 ft. diam. by 10 ft. high.
Air inlets (feeding numerous small tubes)	34 2-in. pipes.
Down tube	44 in. diam.
Down tube at lower end	60 in. diam.
Length of taper in down tube, changing from 44 in. to 60 in. diam	20 ft.
Air chamber in lower end of shaft	16 ft. diam.
Total depth of shaft below normal level of head water	about 150 ft.
Normal head and fall	about 22 ft.
Air discharge pipe	7 in. diam.

It is used to supply power to engines for operating the printing department of the cotton mills.

There were three series of tests conducted to determine the efficiency of the compressor, viz.:

1. Three tests at different rates of flow of water, the compressor being as originally constructed.

2. Four tests at different rates of flow of water, the compressor inlet tubes for air being increased by 30 $\frac{3}{4}$-inch pipes.

3. Four tests at different rates of flow of water, the compressor inlet tubes for air being increased by 15 $\frac{3}{4}$-inch pipes.

The water used on the tests was measured by a weir 10 feet in width, and is illustrated in the accompanying cuts (Figs. 203–207), three hook gauges being employed for determining the head, two being read by Prof. C. H. McLeod, of the McGill University, and the other by William O. Webber, of Boston. The compressed air delivered was measured by air meters, properly calibrated, and read by J. M. Cameron, of Philadelphia, and Taylor Gleaves, of Lynchburg, Va.

The contained moisture in the air was measured by carefully standardized instruments, read by Prof. R. J. Durley, of McGill University, and J. Herbert Shedd, of Providence, R. I., Mr. Jay M. Whitham, of Philadelphia, Pa., having general oversight of the tests. The head of water, condition of the air, pressures, temperatures, and quantities were read at five-minute intervals. The tests extended over a period of two days, and the results are as follows:

Items.	Compressor Head Air Inlets.		
	Original.	Inc'd by 15 ¼-in. Pipes.	Inc'd by 30 ¼-in. Pipes.
Flow of water, cu. ft. per minute	3,772	3,507	3,628
Available head in ft	20.538	20.119	19.997
Gross water, H. P	146.3	132.2	136.9
Cu. ft. air delivered at atmospheric pressure per min.	864	765	901
Pressure of air at compressor, lbs	51.9	51.9	53.7
Atmospheric pressure, lbs	14.51	14.42	14.47
Effective work done in compressing air, H. P	83.3	73.5	88.2
Percentage of efficiency of compressor	56.8	55.5	64.4
Temperature of external air, deg. Fahr	68.3	64.7	57.7
Temperature of water and compressed air, deg. Fahr.	66	66.2	65.5
Ratio of water to recovered air by volumes	4.37	4.58	4.03
Moisture in external air, p. c. of saturation	61	63	77.5
Moisture in air after compression, p. c. of saturation.	41.5	39	44

This table, when the flow was about 3,600 cubic feet per minute, showed a decided economic advantage by the use of

FIG. 203.

30 ¾-inch extra air inlet pipes, the efficiency increasing from 56.8 per cent. for the original setting to 64.4 per cent. when modified.

Items.	Compressor Head Air Inlets.		
	Original.	Inc'd by 15 ¾-in. Pipes.	Inc'd by 30 ¾-in. Pipes.
Flow of water, cu. ft. per minute	4,066	4,292	4,310
Available head in ft	20.348	19.509	19.578
Gross water, H. P	156.2	158.1	159.4
Air delivered at atmospheric pressure, cu. ft. min	967	1,148	998
Pressure of air at compressor, lbs	53.2	53.3	53.7
Atmospheric pressure, lbs	14.51	14.41	14.45
Effective work done in compressing air, H. P	94.3	111.74	97.7
Efficiency of compressor, p. c	60.3	70.7	61.3
Temperature of external air, deg. Fahr	66.4	65.2	61.4
Temperature of water and compressed air, deg. Fahr.	66.4	66.5	65.5
Ratio of water to recovered air by volumes	4.20	3.74	4.32
Moisture in external air, p. c. of saturation	71	68	65
Moisture in air after compression, p. c. of saturation.	38.5	35	31

This table shows, when the flow of water is about 4,200 cubic feet per minute, that the economy is highest when only 15 extra air tubes are employed, the efficiency increasing from 60.3 per cent. for the original setting, to 70.7 per cent. as modified.

Items.	Compressor Head Air Inlets.		
	Original.	Inc'd by 15 ¾-in. Pipes.	Inc'd by 30 ¾-in. Pipes.
Flow of water, cu. ft. per minute	4,408	4,700	4,600
Available head in ft	19.929	19.309	19.411
Gross water, H. P	165.8	171.4	168.6
Air delivered at atmospheric pressure, cu. ft. min	1,091	1,103	1,070
Pressure of air in compressor, lbs	53.7	52.9	53.6
Atmospheric pressure, lbs	14.51	14.40	14.44
Effective work done in compressing air, H. P	107	106.8	104.5
Efficiency of compressor, p. c	64.5	62.2	62
Temperature of external air, deg. Fahr	59.7	65	61.8
Temperature of water and compressed air, deg. Fahr.	67	66.5	66
Ratio of water to recovered air by volumes	4.04	4.26	4.30
Moisture in external air, p. c. of saturation	90	60.5	68
Moisture in compressed air, p. c. of saturation	29	31.2	38

This table shows, when the flow is about 4,600 cubic feet per minute, that there is no economic advantage by increasing the air inlet area in this particular installation.

Items.	Compressor Head Air Inlets.	
	Increased by 15 ¾-in. Pipes.	Increased by 30 ¾-in. Pipes.
Flow of water, cu. ft. per minute	5,058	5,345
Available head in ft.	18.747	19.309
Gross water, H. P.	179.1	194.9
Air delivered at atmospheric pressure, cu. ft. min.	1,165	1,115
Pressure of air in compressor, lbs.	53.3	52.7
Atmospheric pressure, lbs.	14.44	14.40
Effective work done in compressing air, H. P.	113.4	107.8
Efficiency of compressor, p. c.	63.3	55.4
Temperature of external air, deg. Fahr.	64.2	65.2
Temperature of water and compressed air, deg. Fahr.	66	66.5
Ratio of water and recovered air by volumes.	4.34	4.79
Moisture in external air, p. c. of saturation	63	63.5
Moisture in air after compression, p. c. of saturation.	30	33.5

This table shows that a flow of 5,000 or more cubic feet of water is in excess of the capacity of the plant.

FIG. 204.

FIG. 205.

These four tables may be summarized as follows:

Items.	Flow of Water, cu. ft. per min.	Efficiency, per cent.
Original setting	3,772	56.8
" "	4,066	60.3
" "	4,408	64.5
Air inlets increased by 15 ¾-in. pipes	3,507	55.2
" " " " "	4,292	70.7
" " " " "	4,700	62.2
" " " " "	5,058	63.3
" " " 30 ¾-in. pipes	3,628	64.4
" " " " "	4,310	61.3
" " " " "	4,600	62.0
" " " " "	5,345	55.4

The tests show:

1. That the most economical rate of flow of water with

this particular installation is about 4,300 cubic feet per minute.

2. That this plant has shown an efficiency of 70.7 per cent. under such a flow, which we consider excellent for a first installation.

3. That the compressed air contains only from 30 to 20 per cent. as much moisture as does the atmosphere.

4. That the air is compressed at the temperature of the water.

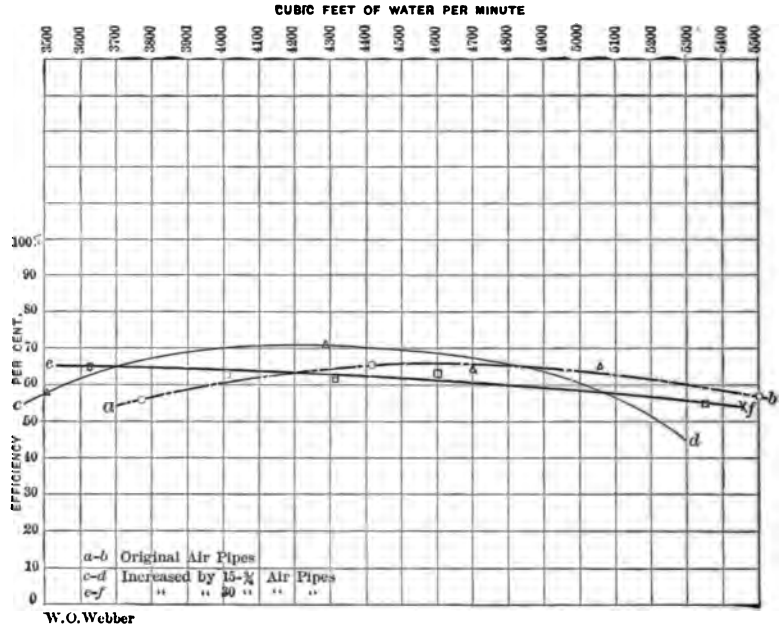

FIG. 206.—MAGOG HYDRAULIC AIR COMPRESSOR.

The results of these tests, together with two others made by Professor McLeod on the same plant on August 13, 1896, in its original condition, are shown on the above diagram, Fig. 206.

In the tests at Magog we recovered 81 horse-power, using an old Corliss engine without any changes in the valve gear as a motor; this would represent a total efficiency of work, recovered from the falling water, of 51.2 per cent.

When the compressed air was preheated to 267 degrees Fahrenheit before being used in the engine, 111 horse-power was recovered, using 115 pounds coke per hour, which would equal about 23 horse-power. The efficiency of work recovered from

the falling water and the fuel burned would be, therefore, about 61½ per cent. On the basis of Professor Riedler's experiments, which require only about 425 cubic feet of air per brake horse-power per hour, when preheated to 300 degrees Fahrenheit and used in a hot-air jacketed cylinder, the total efficiency secured would have been about 87½ per cent.

The second compressor on the Taylor principle is located on Coffee Creek, to the south of Ainsworth, British Columbia. The available head of water is 107.5 feet. The down-flow pipe is 33 inches in diameter. The shaft is 32 square feet area and 210 feet deep. The maximum volume of water is 4,200 cubic feet per minute, and would represent, at 71 per cent. efficiency, 587 horse-power. This compressor is expected to utilize about 5,100 cubic feet of free air per minute, or 734 cubic feet of compressed air at 87 pounds pressure, and give an air-motor output of 360 horse-power. It is possible, however, that this plant may not give as high percentages as this, as the water passages are of smaller areas than those at Magog.

Three other plants are now under construction, one at Peterborough, Ontario; one at Norwich, Conn., and one in the Cascade Range, State of Washington.

The plant at Peterborough, Ontario, for the Government of the Dominion of Canada, is to be used in connection with one of the locks on the Trent Valley Canal, the chief dimensions being as follows:

Head of water	14 feet.
Gauge pressure	25 pounds.
Diameter of compressor pipe	18 inches.
Diameter of shaft	42 inches.
Depth below tailrace	64 feet.

The whole plant is enclosed in the masonry wall of the lock, the usual rock chamber in the bottom of the shaft being built in concrete, and only a few feet below the water level of the lock.

At Norwich, Conn., at what is known as the Tunnel Privilege on the Quinebaug River, the plant will give 1,365 horse-power of air at a pressure of 85 pounds per square inch.

Head of water	18½ feet.
Diameter of shaft	24 feet.
Diameter of pressure pipe	13 feet.
Depth of shaft	208 feet.

The air will be transmitted a distance of four miles, with a loss in transmission not exceeding 2 per cent., through 16-inch pipe, which will be laid with flanged joints and rubber gaskets.

The plant which is being constructed in one of the canyons of the Cascade Range of mountains in the State of Washington

FIG. 207.

will give 200 horse-power of air at a pressure of 85 pounds per square inch.

Head of water.....45 feet.
There is no shaft, as the apparatus is constructed against the vertical walls of the canyon.
Diameter of compressor pipe.....3 feet.
Diameter of up-flow pipe.....4 ft. 9½ in.

The capacity of the plant is based on 2,000 miner's inches of water, equal to 53.2 cubic feet per second. The total height of this apparatus is about 260 feet.

DISCUSSION.

Prof. R. H. Thurston.—My attention was recently called to this singular system of air compression by Mr. R. W. Gilder, editor of the *Century Magazine*, before I had any exact knowledge of the actual work in progress. My first impression was that it must be a most extraordinarily inefficient system. The idea was not new, and I dismissed the matter from my mind as of no importance. Since then I have heard enough to indicate that it is not to be so promptly dropped, and the figures here given, which I accept as substantially accurate, of course, are so remarkably in excess of anything that I had anticipated that I, and I am sure every one of us, will desire further information. I should have expected an efficiency of utilization of the fall of perhaps 40 per cent. as a maximum. If the figures here found, 60 to 70 per cent., can be relied upon as obtainable in practice with as little experience as has yet been had in designing the apparatus, it looks extremely probable that the system will rival the best existing constructions of orthodox forms, and the problem of the engineer seeking motive power for air compression will be simply one of relative costs of construction and of interest and maintenance accounts.

As a method of utilizing a fall for power purposes it is, of course, a very different proposition. There must be taken into account the net result of transmission and transformation of energies all along the line, from dam and reservoir to point of delivery, from the prime mover to the machinery of the works to be operated. In the present case, nothing is stated in the paper relative to the final efficiency of the plant; but if the air-compression system have an efficiency averaging 70, and the compressed-air engine delivers 60 per cent. of its energy to the machinery of the mills, the total efficiency, $.70 \times .60 = 0.42$ per cent., which is to be compared with the efficiency of a turbine directly actuated by the fall. This should be 50 per cent. higher and may be double that of the compressed-air system as here described. Should future improvements in design and construction permit a guarantee of even 80 per cent. for the air compressor and an equal amount for that of the compressed-air engines, the resultant 64 per cent. is to be compared with the 80 per cent. to be at the same time and place obtainable from the turbine.

Costs of dam, flume, and other construction, and maintenance,

must also be compared before we can determine precisely what are the relative values, commercially, of the usual and the proposed systems. In hydraulic work, the costs of construction are pretty apt to count for a great deal in deciding such matters as this of choice between rival systems of power production.

I hope that we may have accounts, later, in full detail, financial as well as mechanical, of the operation of the several other plants which are, and are to be, laid down on this plan. Mr. Webber will do the profession a service in securing complete particulars for the information of the members of the Society.

*Mr. Wm. O. Webber.**—In regard to the efficiency of compressed-air transmission, as brought up by Dr. Thurston's criticism of my paper, would submit the following figures, which are well borne out by the results of Gutermuth's, Riedler's, and Mekarski's tests, which can be found in *Kent's Pocket Book*:

ESTIMATE OF POWER TRANSMISSION AVAILABLE FROM A WATER-FALL BY DIFFERENT METHODS OF DEVELOPMENT.

	HORSE-POWER.
Given horse-power of water	1,000
Wheels at 85 per cent. efficiency	850
Shafting, pulleys and belts at 80 per cent	680
or 68 per cent., wheels being at full gate, and the minimum loss in shafting being allowed. With wheels as usually run at part gate, the result would be as follows:	
Given horse-power of water	1,000
Wheels at 75 per cent. efficiency	750
Shafting, pulleys and belts, 50 per cent. (average)	375
or 37½ per cent. of the whole power, both being directly at the site of the water power.	
In order to transmit power to a distance, we must take again:	
Horse-power of water	1,000
Wheels at 85 per cent	850
Generator at 92 per cent	780
Transformers at 92 per cent	720
Line at 95 per cent	680
Convertors at 92 per cent	625
or about 62½ per cent. of the whole, and with direct-connected motors at 90 per cent	565
or 56½ per cent. of the whole, or if belted at 90 per cent	508
or say 51 per cent. of the whole.	
Hydraulic air:	
Horse-power of water	1,000
Hydraulic compressor at 75 per cent	750
Pipe line efficiency at 98 per cent	735

* Author's closure, under the Rules.

	HORSE-POWER.
Reheating dry air, add 50 per cent. / Moistening " " " 50 per cent. } = 100 per cent.....	1,470
Air engine or motors at 78 per cent.....	1,145
or 114.5 per cent., and if belted at 90 per cent.....	1,030
or 103 per cent. of whole as a *resultant* effect.	

The weight of a cubic foot of compressed air at 85 pounds and at 70 degrees Fahr., 509 pounds.

One thousand horse-power would represent 750,000 cubic feet of 85 pounds air per hour. This would equal 382,000 pounds of air, and as one pound of air will absorb .58 pound of water, we would require 221,500 pounds of water per hour.

The labor represented by forcing 221,500 pounds of water per hour equals 3,700 pounds per minute against 85 pounds pressure = 195.5 feet would be $\frac{195.5 \times 3{,}700}{33{,}000} = 22$ horse-power about, and as pumps give an efficiency of 50 per cent. = 44 horse-power of work by pump, or 4.4 per cent. of the whole 1,000 horse-power. This is therefore to be deducted. The coal used in heating the air, which is about 1 pound per horse-power per hour, would also represent an amount of work equal to 75 horse-power, or 7½ per cent. of the whole 1,000 horse-power. This added to the 4.4 per cent. as above, would equal an amount of 13 per cent. to be deducted = 87 per cent. of the whole horse-power, or 1,030 × 87 per cent. = 896 horse-power, or 89.6 per cent. as a final result of all, as against 56½ per cent. by electricity, or 68 per cent. by water wheels at their best, or 37½ per cent. by water wheels at their average.

That our results are within the bounds of reason is shown by the fact that 75 per cent. × 98 per cent. × 200 per cent. × 78 per cent. × 87 per cent. = 99.5 per cent.

Some recent tests which have been made on a large plant in Germany are reported to have given 90 per cent. efficiency for the hydraulic air compressor, which is above anything that we have hoped to get.

In regard to the cost of construction of dams, flumes, and other things, the cost of the dam would be precisely what it would be for any other development, and the 1,350 horse-power compressor at Norwich will cost not to exceed $50 per horse-power all told.

As soon as we get some figures on the cost of operation on a large scale, I will be pleased to contribute them to the Society.

No. 895.*

EFFICIENCY TESTS OF A ONE-HUNDRED-AND-TWENTY-FIVE-HORSE-POWER GAS ENGINE.†

[*Second Paper.*]

BY C. H. ROBERTSON, LAFAYETTE, IND.

(Junior Member of the Society.)

1. AT the December, '99, meeting of the Society there was presented a paper on the subject, "An Efficiency Test of a One-hundred-and-twenty-five-horse-power Gas Engine." ‡ This test was run in the spring of that year, and was the second of a series which had been begun in the spring of '98. In presenting the paper, the author stated that still further tests were under contemplation. These "further tests" were run in the spring immediately following the meeting. It will thus be seen that tests were run in the spring of '98, '99, and 1900. Results of the tests of '98 were not published. Result of tests of '99 were reported in the above-mentioned paper, and the object of this paper is to give some of the results of tests (the third in the series) run in April and May, 1900.

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* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† For further discussions on this topic, consult *Transactions* as follows:

No. 151, vol. v., p. 340: "Report on Natural Gas."

No. 220, vol. vii., p. 680: "Substitutes for Steam." G. H. Babcock.

No. 836, vol. xxi., p. 275: "New Method for Constructing Entropy-Temperature Diagram for Gas or Oil Engines." H. T. Eddy.

No. 771, vol. xix., p. 477: "Thermodynamics without the Calculus." George Richmond.

No. 831, vol. xxi., p. 172: "Experiments on Using Gasoline Gas for Boiler Heating." H. Poole.

No. 861, vol. xxi., p. 961: "Gas Engine Hot Tube as an Ignition-Timing Device." W. T. Magruder.

No. 875, vol. xxii., p. 152: "Efficiency of a Gas Engine as Modified by Point of Ignition." C. V. Kerr.

No. 879, vol. xxii., p. 312: "A New Principle in Gas-engine Design." C. E. Sargent.

‡ "An Efficiency Test of a 125-horse-power Gas Engine," *Trans.*, vol. xxi., p. 396, No. 843.

The Plant.

2. The plant tested is owned by the Merchants' Electric Lighting Association, of LaFayette, Ind. It was installed in the winter of '97 and '98, and had for its motive power two 125-horse-power Westinghouse gas engines, with the appropriate electrical machinery for generating commercial electric light and power current. The gas engines are of the vertical three-cylinder type, and work on the Beau De Rochas or Otto cycle. The pistons have a diameter of thirteen and a stroke of fourteen inches.

3. The gas and air on its way to the engine passes through what is known as the mixing-valve chamber, at the top and bottom of which are two horizontally moving levers, with pointers swinging over graduated arcs. The upper lever, by turning a cylindrical valve within, changes the area of the port for admitting gas. The lower lever, by means of a similar device, changes the area of the air-admission ports. The graduations on the arcs are such as to give the ratio of gas to air which has passed to the interior of the mixing valve. Without in any way affecting the above setting, a flyball governor is so connected to the mixing valves as to give them a motion in the direction of their length. This motion is utilized in varying the area of the ports through which the mixture passes on its way to the cylinders. It is thus seen that the speed of the engine is controlled by throttling the mixture of gas and air without in any way affecting its quality, and that a working impulse is given every two-thirds of a revolution, whether the load is heavy or light.

4. One of the cylinders of the engine is so arranged that it can be quickly and easily converted into a single-acting compressed-air engine. By its use, momentum enough is secured to lightly compress a charge in one of the remaining cylinders, which, on ignition, augments the speed, so that the air cylinder may be thrown into its normal working condition. A back view of the engine is shown by Fig. 208. The exhaust-cam levers are seen at the top of the crank case, and the compressed-air supply pipe between the fly-wheel and the right-hand cylinder. In the lower left-hand corner of the picture may be seen the belt-driven air compressor. The air is stored in steel cylinders under a pressure of 160 pounds gauge.

5. The cylinder walls are kept cool by the use of water-jackets. The plant is so piped that city water may be used; but ordinarily

a small belt-driven pump takes the water from a cistern below the repair-room floor, and, after passing it through the jackets, delivers it to the top of a cooling tower.

6. The plant is located in a portion of the city near which are many residences. It was, therefore, a matter of importance that the noise of exhaust should not be offensive. The exhaust pipe was connected underground to a cistern outside the

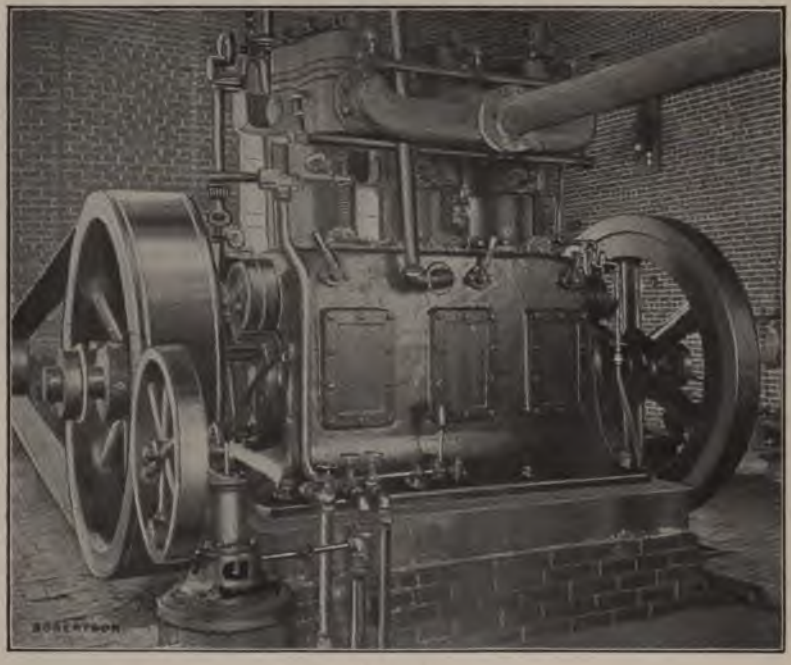

FIG. 208.

building, open to the air at its top through a tile of ten inches diameter.

7. Two circuit breakers are mounted in each igniter plug, one being held in reserve for emergency. The igniter is operated by a cam of spiral form, with a radial notch. It is so connected that just as the cam reaches its greatest throw the circuit is completed within the cylinder, to be broken an instant later by the dropping of the igniter rods into the notch of the cam. For a more complete description of the building and machinery the reader is referred to the original paper. (See reference to No. 843 *supra*.)

Changes in the Plant.

8. Since the tests reported in '99 were run, a number of changes have been made in the plant. On account of the uncertainty of the supply of natural gas, one of the gas engines has been replaced by a 150-horse-power Westinghouse steam engine, and a boiler plant of Sterling water-tube boilers. The second gas engine was taken out and completely overhauled and remodelled by the builders. This engine, upon being reinstalled, was run for about two weeks, in order that it might be adjusted and

FIG. 209.

gotten into good condition, after which the tests here given were run. A picture of the plant as it now appears is shown by Fig. 209, and a plan of the ground floor by Fig. 210.

9. The principal changes in the gas engine were as follows:

First: Cylinder oil was substituted in the crank case for a mixture of cylinder oil and water, as previously.

Second: Larger openings were provided for the supply of air to the mixing-valve.

Third: External pipe connections were supplied for passing the cooling water from the head to the jacket of the cylinder, rather than have it pass directly through cored holes, as before.

Fourth: The cooling-water pipes were made larger.

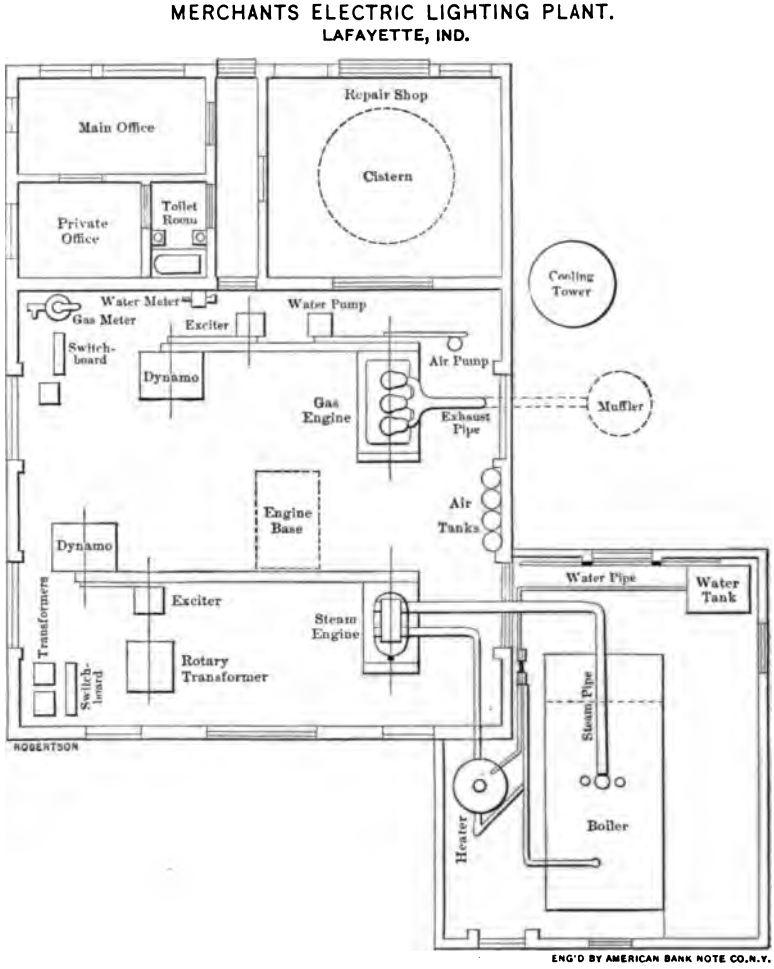

FIG. 210.

Fifth: The old cylinders were replaced by new.

Sixth: Various minor details of mechanism were improved and refitted.

Auxiliary Apparatus, Calculations, etc.

10. A description of apparatus, methods of observation, calibration, and calculation may be found in appendices as follows:

(I.) Tuning-fork Chronograph for determining speed variation, paragraph 25.

(II.) Heating Value of Gas, paragraph 33.
(III.) Pyrometer for Exhaust Temperatures, paragraph 36.
(IV.) Observation and Computations, paragraph 40.
(V.) Miscellaneous Apparatus, paragraph 57.

The Tests.

11. The specific object of the present paper is to make a rather complete statement of the results secured from those tests on the gas engine which were considered as the most reliable. The tests selected were, first, one of six-hour duration, in which the load was that ordinarily found on the station on Saturday night, and, second, a series of five short tests, in which the load was absorbed and measured by means of a Prony brake.

12. Acknowledgment should be made of the efficient and painstaking service of Messrs. J. H. Berryhill, H. S. Colburn, C. D. Park, M. W. Priseler, and M. R. Wells, who, as senior students in Purdue University, and under the supervision of the writer, secured the data which serves as the basis of this paper.*

13. A brief outline of the points investigated is as follows:

(1) Miscellaneous Items;
  (*a*) Heating Value of Gas.
  (*b*) Temperature of Exhaust.
  (*c*) Speed Regulation.
  (*d*) Best Proportion of Gas and Air.
(2) Power Developed:
  (*a*) Indicated Horse-Power (I. H. P).
  (*b*) Brake Horse-Power (B. H. P).
  (*c*) Electrical Horse-Power (E. H. P).
  (*d*) Frictional Horse Power (F. H. P).

* "A Series of Efficiency Tests on a 125-horse-power Gas Engine and a 150-horse-power Steam Engine under Similar Conditions of Operation." Graduating thesis of J. H. Berryhill, B.S., H. S. Colburn, B.S., C. D. Park, B.S., and M. R. Wells, B.S., 1900.

"A Determination of the Speed Variation of a 125-horse-power Gas Engine." Graduating thesis of M. W. Priseler, B.S., 1900.

The writer desires to acknowledge the assistance of Mr. G. A. Young, B. S., who aided greatly in the supervision of certain parts of the work, and in reduction of data; also the assistance of Messrs. E. B. Smith and A. B. Golden, who gave careful attention to all electrical measurements; also the many helpful suggestions of Mr. W. P. Flint, who was present as a representative of the Westinghouse Machine Company during the progress of the tests.

Acknowledgment is also made of the many courtesies of Mr. Charles Dixon, the manager of the Merchants' Electric Lighting Association.

3. Resulting Efficiencies:

(*a*) Thermal efficiency of engine

$$= \frac{\text{B. T. U. equivalent to a H. P. hour}}{\text{B. T. U. in gas burned per B. H. P. hour}}.$$

(*b*) Thermal efficiency of plant

$$= \frac{\text{B. T. U. equivalent to a H. P. hour}}{\text{B. T. U. in gas burned per E. H. P. hour}}.$$

(*c*) Mechanical efficiency $= \frac{\text{B. H. P}}{\text{I. H. P}}$.

4. Heat Balance:

(*a*) Heat Given to Water-jacket.

(*b*) Heat Consumed in Work.

(*c*) Heat Exhausted and Radiated.

The Six-hour Test.

14. *Miscellaneous Facts.*—In the tests reported at the December, 1899, meeting of the Society, no attempt was made to put the engine in particularly good condition, nor was any attempt made to give the plant special attention during the test, the desire being to determine its performance under the conditions and care which it received in everyday practice. On the tests here reported, this was not true. The engine had just been received from the factory, where it had been thoroughly overhauled, and, after being erected in the plant, it was adjusted by a representative of the company, who was present throughout the tests.

15. The test began at 6 P.M., and ended at 12 P.M. (May 5, 1900).

At about 6.15 the igniter on the middle cylinder was accidentally short-circuited by a metal hook on an indicator cord. The speed of the engine decreased slightly before the trouble was discovered and remedied.

At about 7.45 the belt slipped to such an extent as to cause the lights to grow dim before it could be tightened.

At about 9.45 it was found that pounding, due to premature ignition, was taking place in the third cylinder, and more jacket-water was then passed to reduce the temperature of the cylinder.

Several times during the test indicator cords broke, causing the loss of i[illegible]cards.

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A deflectometer was placed on the mixing valve, but its readings were not used in calculating results.

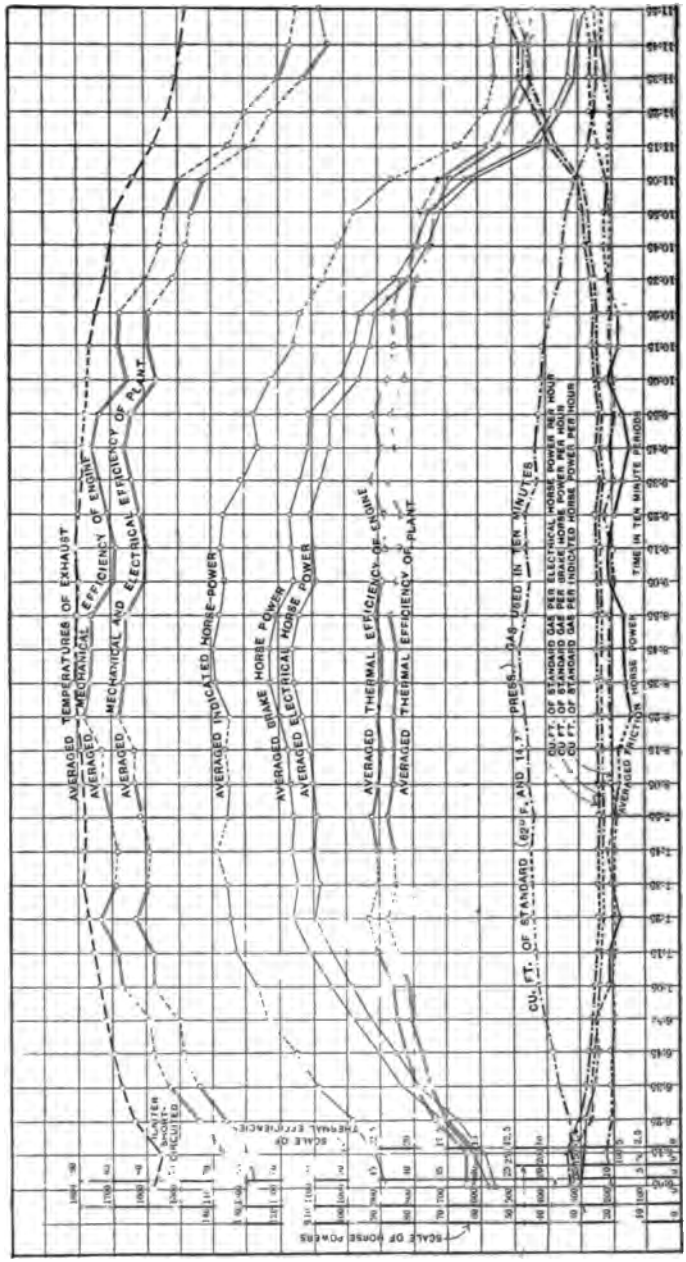
An attempt was made to determine the per cent. of carbon dioxide (CO_2) in the exhaust gas by means of an Arndt econometer. The results were not satisfactory.

16. *Results.*—The running log and calculated results of the six-hour test may be found in Table I. The principal items of the table are shown graphically by Fig. 211. The methods of observation and calculation are given in paragraph 40. Indicator cards are shown by Figs. 212 to 215. The relation between the gas per indicated horse-power, per brake horse-power, and per electrical horse-power, and the corresponding horse-powers is shown by Fig. 216. The points selected in drawing these curves were those of every tenth reading of the test (Table I).

TABLE II.

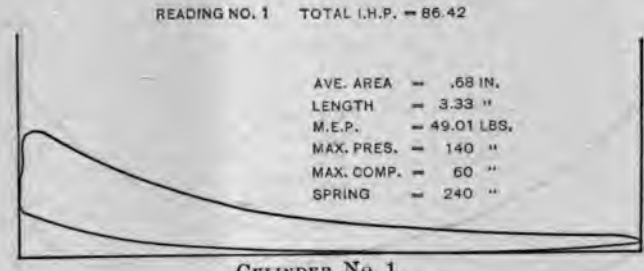
Résumé of Data.	Six-hour Test.			Five Short Tests.	
	Average of Test	Lowest of Test	Highest of Test	Lowest of Tests	Highest of Tests
Indicated horse-power	113.12	51.69	142.37	18.57	164.22
Brake horse-power	92.19	30.81	122.56	0	148.17
Electrical horse-power	87.12	28.77	115.96		
Frictional horse-power	20.93	14.72	31.01	17.06	21.05
Mechanical efficiency of engine (per cent.)	79.39	57.38	89.05	0	87
Standard gas per indicated horse-power hour	10.62	9.70	13.99	9.87	25.8
Standard gas per brake horse-power hour	13.69	11.29	24.37	11.51	——
Standard gas per electrical horse-power hour	14.49	11.97	26.10	——	——
Thermal efficiency of engine (per cent.) B. T. U. eq. to B. H. P. / B. T. U. in gas	20.05	10.76	23.24	——	22.8
Thermal efficiency of plant (per cent.) B. T. U. eq. to E. H. P. / B. T. U. in gas	18.94	10.05	21.92	——	——
British Thermal Units per I. H. P. per minute	171.66	156.79	236.13	——	——

17. A résumé of the data is presented in the first part of Table II. There it may be seen that the average indicated horse-power for the test was about 113, the highest being 142 and the lowest 52. Corresponding brake horse-powers were 92, 123, and 31. The frictional horse-power varies from 15 to 31, the average being about 21. The mechanical efficiency is, of course, low at low power. The highest figure, 89 per cent., is certainly good for a gas engine. The gas per indicated horse-power became as low as 9.7 and per brake horse-power 11.29. The averages for the test in regard to these two items are 10.62 and 13.69 respectively.

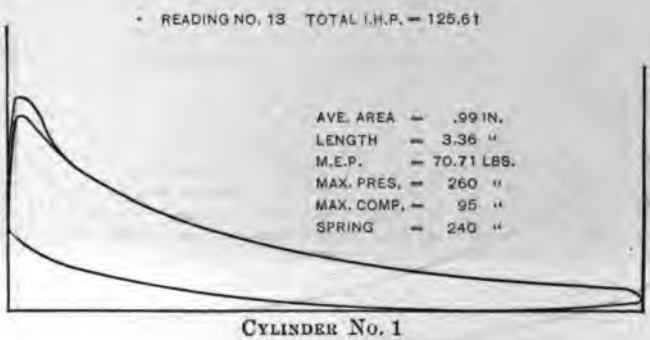

AVERAGED TEMPERATURES OF EXHAUST
AVERAGED MECHANICAL EFFICIENCY OF ENGINE
AVERAGED MECHANICAL AND ELECTRICAL EFFICIENCY OF PLANT
AVERAGED INDICATED HORSE-POWER
AVERAGED BRAKE HORSE POWER
AVERAGED ELECTRICAL HORSE POWER
AVERAGED THERMAL EFFICIENCY OF ENGINE
AVERAGED THERMAL EFFICIENCY OF PLANT
CU. FT. OF STANDARD (62° F. AND 14.7 PRESS.) GAS USED IN TEN MINUTES
CU. FT. OF STANDARD GAS PER ELECTRICAL HORSE POWER PER HOUR
CU. FT. OF STANDARD GAS PER BRAKE HORSE POWER PER HOUR
CU. FT. OF STANDARD GAS PER INDICATED HORSE POWER PER HOUR
AVERAGED FRICTION HORSE POWER
TIME IN TEN MINUTE PERIODS
SCALE OF HORSE POWERS
SCALE OF THERMAL EFFICIENCIES
SCALE OF EXHAUST TEMPERATURES OF.
SCALE OF MECHANICAL EFFICIENCIES AND CU. FT. OF DECIMALS P.
STANDARD GAS PER I.H.P. B.H.P. AND E.H.P. PER HOUR
SCALE OF STANDARD GAS USED N 10 MINUTES

Robertson

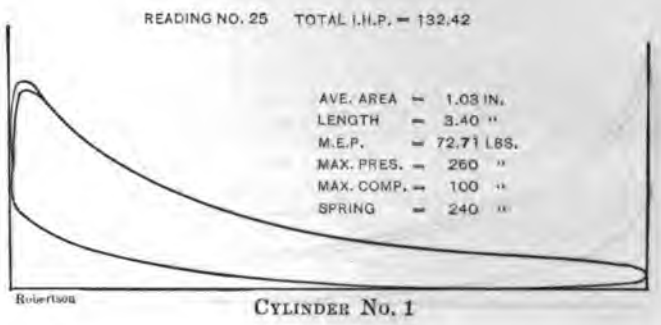
FIG. 211.



CYLINDER No. 1



CYLINDER No. 1



CYLINDER No. 1

FIG. 212.

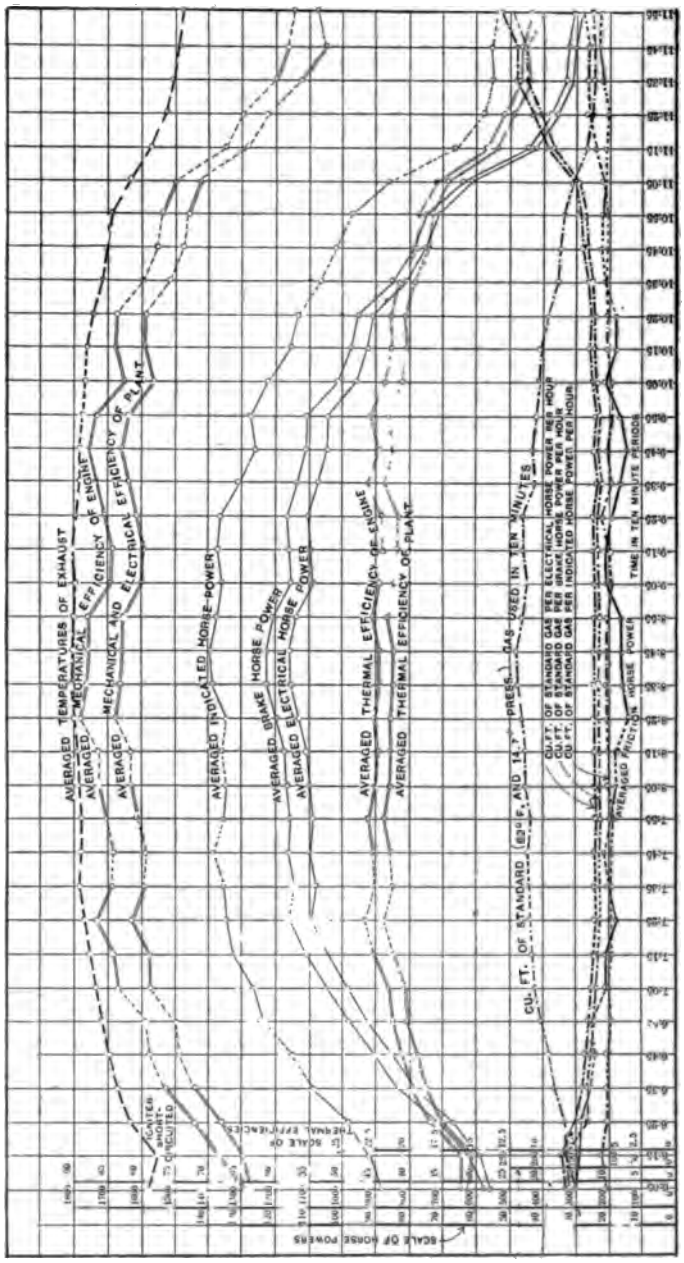
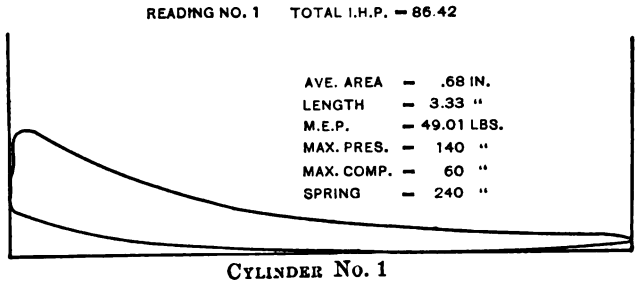
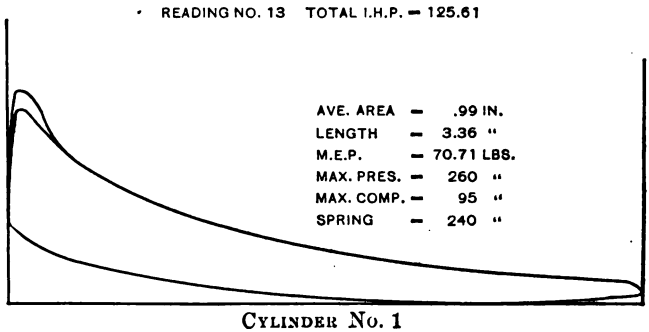

AVERAGED TEMPERATURES OF EXHAUST
AVERAGED MECHANICAL EFFICIENCY OF ENGINE
AVERAGED MECHANICAL AND ELECTRICAL EFFICIENCY OF PLANT
AVERAGED INDICATED HORSE-POWER
AVERAGED BRAKE HORSE POWER
AVERAGED ELECTRICAL HORSE POWER
AVERAGED THERMAL EFFICIENCY OF ENGINE
AVERAGED THERMAL EFFICIENCY OF PLANT
AVERAGED FRICTION HORSE POWER
CU. FT. OF STANDARD (60° F. AND 14.7 PRESS.) GAS USED IN TEN MINUTES
CU. FT. OF STANDARD GAS PER ELECTRICAL HORSE POWER PER HOUR
CU. FT. OF STANDARD GAS PER BRAKE HORSE POWER PER HOUR
CU. FT. OF STANDARD GAS PER INDICATED HORSE POWER PER HOUR
TIME IN TEN MINUTE PERIODS
SCALE OF HORSE POWERS
SCALE OF THERMAL EFFICIENCIES
CENTER MONITOR CIRCUITED
SCALE OF TEMPERATURES OF
SCALE OF STANDARD GAS USED IN 10 MINUTES

Fig. 211.

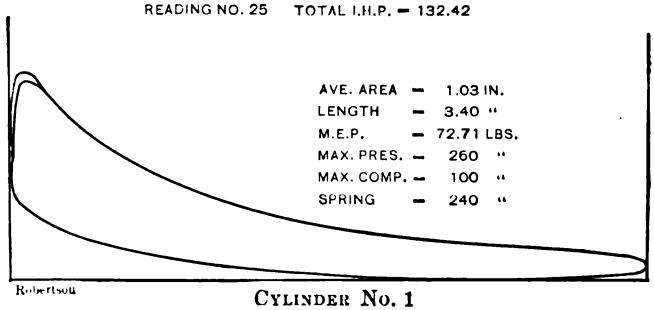
Robertson



CYLINDER No. 1

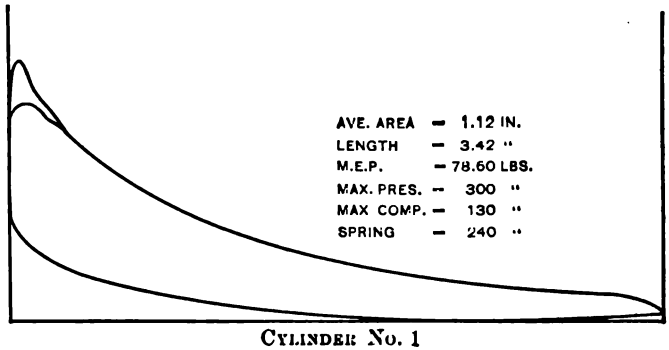


CYLINDER No. 1

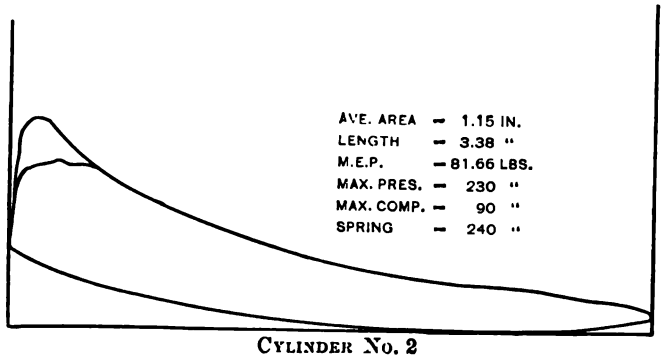


CYLINDER No. 1

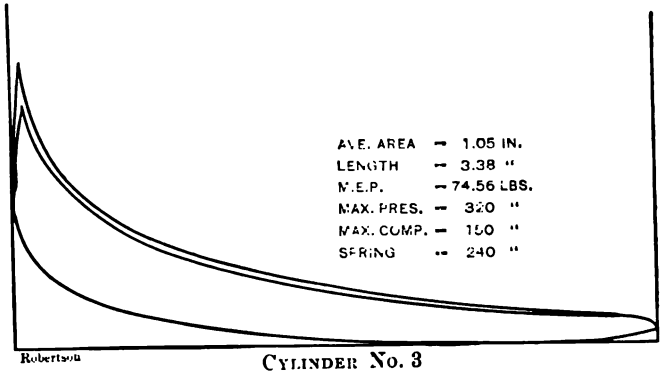
FIG. 212.



CYLINDER No. 1

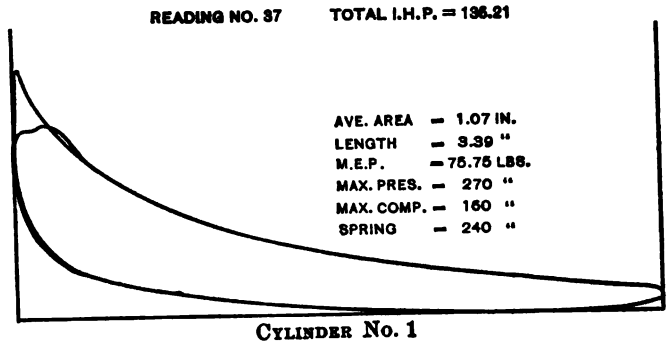


CYLINDER No. 2

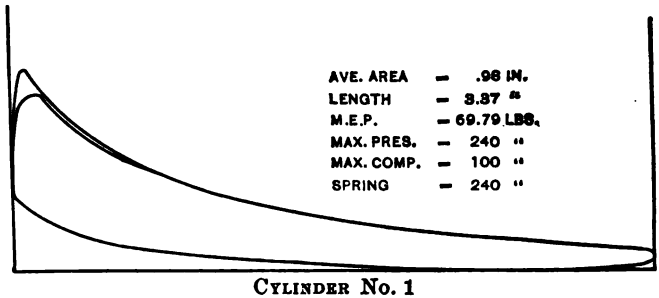


CYLINDER No. 3

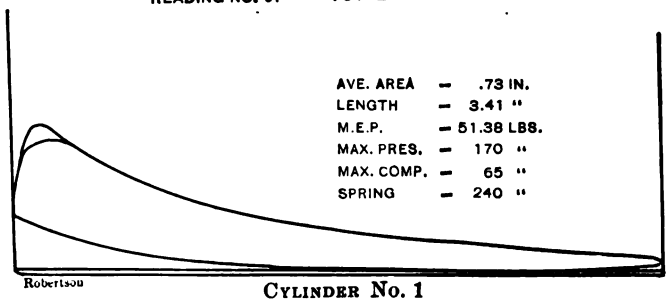
FIG. 213.



CYLINDER No. 1

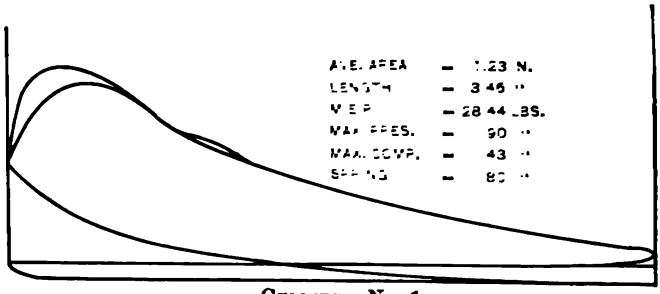


CYLINDER No. 1

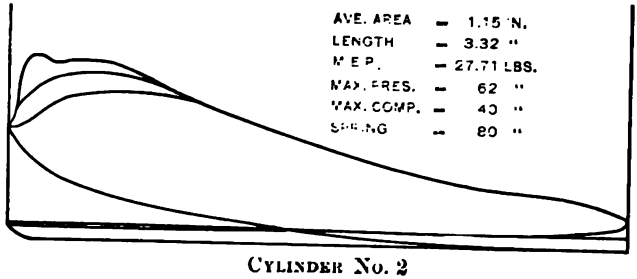


CYLINDER No. 1

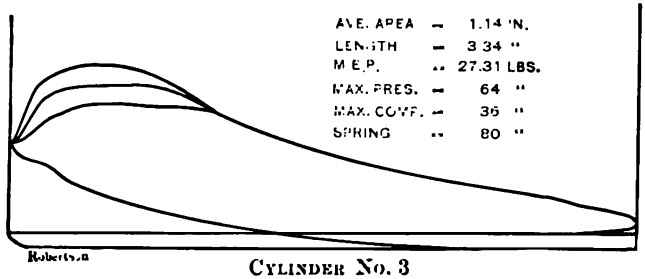
FIG. 214.



CYLINDER No. 1



CYLINDER No. 2



CYLINDER No. 3

FIG. 215.

18. The thermal efficiency of the engine, in terms of brake horse-power, is of interest, and, at its best, shows that nearly one quarter of the energy of the gas is realized at the fly-wheel. The next figure in the table shows that, at its best performance, somewhat more than $\frac{1}{4}$ of the heat of the gas was realized in electrical horse-power at the switchboard. The figures on British thermal units per indicated horse-power per minute are presented for

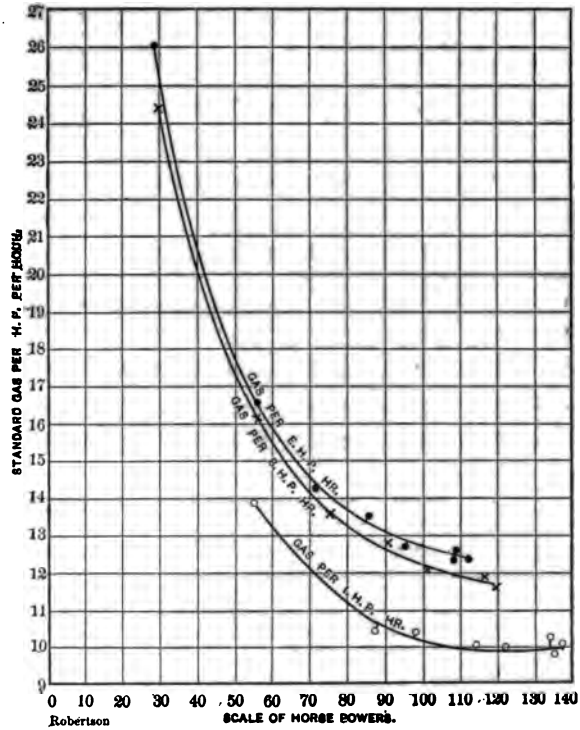

STANDARD GAS PER H. P. PER HOUR.
GAS PER E.H.P. HR.
GAS PER I.H.P. HR.
GAS PER I.H.P. HR.
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
SCALE OF HORSE POWERS.
Robertson

FIG. 216.

the purposes of comparison with steam-engine performances. The best figure in this regard, 157, has never been realized in steam-engine practice.

19. *The Series of Short Tests.*—One of the unexpected things to the author, in the discussion of the paper presented in '99, was the attention given to the approximate determination of the distribution of heat between the equivalent of the indicated horse-power, the jacket, and the exhaust. This suggested the desirability of making a series of short tests, in which each test should be under

TABLE III.

Date and Test of Reading.	Number.	Time.	Difference, Time.	Revolutions per Minute Eng.	Top Counter.	Difference.	Lower Counter.	Difference.	Temperature Cooling H_2O. Initial.	Temperature Cooling H_2O. Final.	Temperature, Room.	Temperature of Mixture.	Gas.	Air.	Deflectometer.	Brake Load, Gross in Pounds.	Gas Measurements. Meter Reading.	Gas Measurements. Difference.	Gas Measurements. Pressure, Inches Mercury.	Gas Measurements. Temperature, Fahrenheit.	Weight of Jacket Cooling H_2O.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Test No. 1, May 5, 1900.	1	11.30	5	266	4,105,848	668	3,641,839	667	52	111	84.5	98	16	6	49.3	0	41,960,887	40	2.2	70	Water loss kept on separate sheet. 2,502.5
	2	11.35	5	264	6,516	661	2,506	661	52	126	80.5	98	16	6	49.3	0	927	37	2.2	70	
	3	11.40	5	265	7,177	661	3,167	662	52	133	80	98	16	6	49.3	0	964	41	2.2	70	
	4	11.45	5	262	7,898	664	3,820	664	52	134	80.5	98	16	6	49.5	0	1,005	37	2.2	70	
	5	11.50	5	267	8,502	665	4,493	664	52	125	82	98	16	6	49.5	0	1,042	36	2.2	70	
	6	11.55	5	267	9,167	664	5,157	664	52	130	82	98	16	6	49.5	0	78	39	2.2	70	
	7	12.00	5	266	9,881	664	5,821	665	52	130	82	98	16	6	49.5	0	117	39	2.2	70	
	8	12.05	5	267	4,110,495	664	6,486	664	52	130	80	98	16	6	49.4	0	153	36	2.2	70	
	9	12.10	5	266	1,159	664	7,170	664	52	133	82.5	98	16	6	49.2	0	192	39	2.2	70	
	Total ...		40	2,339	.....	.....	.....	5,311	.....	.....	7,320	.....	16	...	4,445	.....	305	305	.....	.....	2,502.5
	Average		4	265.55	.....	665.5	.....	.....	52	133.4	81.33	98	16	6	49.38	0	.....	38.12	2.2	70	
Test No. 2, May 5, 1900.	1	10.30	5	264	4,096,640	658	3,634,130	658	52	131	83	98	16	6	47.9	180	41,960,149	61	1.8	69	Water loss kept on separate sheet. 3,742.5
	2	10.35	5	265	7,308	660	788	659	52	127	84	98	16	6	48	180	210	50	1.8	69	
	3	10.30	5	264	958	660	5,447	660	52	125	82	98	16	6	48	180	360	60	1.8	69	
	4	10.35	5	264	8,618	660	6,107	.....	52	124	82	98	16	6	48	180	320	54	1.8	70	
	5	10.40	5	264	278	659	Out of	.....	52	123	81	98	16	6	48	180	374	56	1.8	70	
	6	10.45	5	265	937	656	order.	.....	52	122	82	98	16	6	48	180	430	54	1.8	70	
	7	10.50	5	263	4,100,593	656	3,637,940	.....	52	122	84	98	16	6	48	180	484	58	1.8	70	
	8	10.55	5	264	1,249	656	786	656	52	122	84	98	16	6	48	180	542	56	1.8	70	
	9	11.00	5	265	1,907	657	886	.....	52	122	84.5	98	16	6	48	180	598	55	1.8	70	
	10	11.05	5	264	2,564	.....	8,564	658	52	122	84	98	16	6	48	180	653	.....	1.8	70	
	Total ...		45	2,642	.....	.....	.....	.....	520	1,245	830.5	.....	16	...	479.9	.....	.....	.....	.....	697	3,742.5
	Average		...	264.2	383.98	.....	.....	.....	52	124.5	83.05	98	16	6	47.99	180	504	.....	1.8	69.7	

Test No. 3, May 5, 1900.	1	9.15	5	263	4,088,324	654	3,626,037	655	54	116	80	100	7/16	6	43.5	420	41,259,060	97	1.6	67	Water logs kept on separate sheet.	4,688
	2	9.20	5	263	4,088,978	654	7,592	654	55	122	80	98	7/16	6	43.5	420	9,147	98	1.6	67		
	3	9.25	5	261.5	9,692	654	8,246	653	55	125	78	98	7/16	6	44	420	245	96	1.6	67		
	4	9.30	5	263.5	0,386	654	8,899	654	53	127	78	98	7/16	6	43	420	341	97	1.6	67		
	5	9.35	5	263	940	653	9,553	653	53	128	77	98	7/16	6	43	420	436	97	1.6	67		
	6	9.40	5	263	1,593	657	0,206	654	53	129	80	98.5	7/16	6	43.5	420	535	95	1.6	68		
	7	9.45	5	262	2,245	653	0,860	.....	53	131	80	98.5	7/16	6	43.8	420	630	97	1.6	68		
	8	9.50	5	263	2,898	653	Out of	.....	52	130	80	98.5	7/16	6	43.2	420	727	97	1.6	68		
	9	9.55	5	263	3,551	653	order.	.....	52	130	79.5	98.5	7/16	6	43.2	420	824	96	1.6	68		
	10	10.00	..	263	4,204	.....	3,631,540	.....	52	130	79	98.5	7/16	6	43.1	420	920	.....	1.6	68		
	Total...		45	2,101.0	5,880	.....	.....	.....	532	1,298	796.5	.....	.....	...	433.3	.....	.....	.....	.....	674		4,688
	Average		..	262.62	201.3	.....	.....	.....	53.2	129.8	79.65	.....	7/16	6	43.33	420	873	.....	1.6	67.4		
Test No. 4, May 4, 1900.	1	2.00	5	259	4,065,081	647	3,605,101	642	62	120	82	92	7/16	6	37	540	41,234,839	111	1.39	68.5	Water logs kept on separate sheet.	5,670.5
	2	2.05	5	259	5,728	646	5,143	630	62	120	83	92	7/16	6	38	540	4,950	116	1.38	69		
	3	2.10	5	259	6,374	647	6,373	.....	62	120	84	92	7/16	6	37.1	540	5,066	114	1.4	70		
	4	2.15	5	259	7,021	648	.....	.....	62	120	84.8	92	7/16	6	37.8	540	5,180	119	1.4	70		
	5	2.20	5	259	7,667	646	.....	.....	62	121	83	92	7/16	6	38.7	540	5,299	117	1.4	70		
	6	2.25	5	259	8,315	647	3,607,912	.....	62	121	83.4	91.4	7/16	6	38	540	5,416	115	1.4	70		
	7	2.30	5	260	8,962	646	Broke	.....	62	122	86	91.4	7/16	6	38.8	540	5,531	116	1.65	70		
	8	2.35	5	259.5	9,608	648	3,608,427	.....	647	121	84	91.6	7/16	6	38.3	540	5,647	113	1.68	70		
	9	2.40	5	259	70,256	646	9,004	.....	646	120	84	91.6	7/16	6	38.3	540	5,760	118	1.7	70		
	10	2.45	..	.....	902	.....	9,710	.....	62	120	84	91.8	7/16	6	39.2	540	5,878	....	1.65	70		
	Total...		45	2,332.5	5,821	.....	.....	.....	.....	1,205	837.9	917.8	.....	...	382.2	.....	1,089	1,089	15.05	696.5		5,670.5
	Average		..	259.16	258.96	.....	.....	.....	.....	120.5	83.72	91.78	7/16	6	38.22	540	.....	103.9	1.505	69.65		
Test No. 5, May 4, 1900.	1	4.50	5	257.5	3,618,183	643	4,079,366	643	62	118	81	98.5	7/16	6	31.3	620	41,237,444	131	1.68	69	Water logs kept on separate sheet.	5,792
	2	4.55	5	257.5	8,826	642	80,009	643	62	125	84	98.5	7/16	6	30.9	620	675	136	1.68	69		
	3	5.00	5	257.5	9,468	642	652	642	62	124	83.7	98	7/16	6	30	620	711	134	1.68	69		
	4	5.05	5	257	0,110	642	1,994	641	62	124	83	98.4	7/16	6	31	620	845	134	1.66	69		
	5	5.10	5	257	0,752	640	1,935	640	62	125	83.9	98.2	7/16	6	29.8	620	970	146	1.66	69		
	6	5.15	5	259	1,393	644	2,575	644	63	125	83	98	7/16	6	31.2	620	8,195	190	1.63	69		
	7	5.30	5	257.5	2,036	642	3,210	643	62	125	81	98	7/16	6	34.6	620	8,351	186	1.65	68.5		
	8	5.25	5	257	2,678	643	3,962	643	62	125	81.4	99	7/16	6	30.8	620	8,387	195	1.65	68		
	9	5.30	5	257	3,321	642	4,505	641	62	125	81	98.3	7/16	6	29.5	620	8,332	197	1.60	68		
	10	5.35	..	256	3,963	.....	5,146	.....	62	124	81.5	98	7/16	6	28.2	620	650	.....	.55	68		
	Total...		45	2,573.0	5,780	.....	5,780	.....	620	1,240	822.5	...	...	...	.....	.....	1,215	.....	15.46	680.5		5,792
	Average		..	257.3	256.88	.....	201.33	.....	62	124	82.25	.....	7/16	6	.....	620	.....	.....	1.546	68.05		

constant horse-power, these horse-powers varying with the different tests from zero to the maximum capacity of the engine, the observed data being such as would permit an accurate determination of this and of other important factors. Accordingly, such a series was attempted, the running logs of which are to be found in Table III. In all, seven tests were run, but the data of two of these were considered unsatisfactory, and so they are omitted in the presentation.

20. In general, the methods of observation and calculation were the same as those described for the six-hour test. Unfortunately, connections for the thermo-electric joints were broken, so that no data were secured for the exhaust temperature.

A summary of the averages from running logs and the calculated results therefrom is given in Table IV. From an examination of this data, it will be seen that tests were run on May 4th and 5th, and, with the exception of the first, all were of 45 minutes duration. The power developed by the engine was absorbed and measured by means of a Prony brake.

Indicator cards from each test are shown by Figs. 217 to 221.

21. The principal calculated results are shown graphically by Figs. 222 to 225. The distribution of heat between the equivalent of the indicated horse-power, the water-jacket, and the exhaust is shown by Fig. 222. This diagram was constructed by first plotting the percentage of heat equivalent to the indicated horse-power against the brake horse-power of the engine. The per cent. of heat absorbed by the jacket was next plotted downward from the top of the same scale, leaving as a difference between the two the amount radiated and exhausted. As might be expected, the per cent. appearing as indicated horse-power increases with an increase of horse-power. The per cent. absorbed by the jacket decreases a little more rapidly than that equivalent to the indicated horse-power increases. This results, of course, in a net increase in the amount radiated and exhausted.

22. At the lowest horse-power of the series (zero brake horse-power) the per cents. in regard to these three factors, equivalent of indicated horse-power, exhaust, and jacket, were, approximately, 10, 32, and 58 respectively. At the highest horse-power (143 brake or 164 indicated) the per cents. in regard to these three factors were 26, 44, and 30.

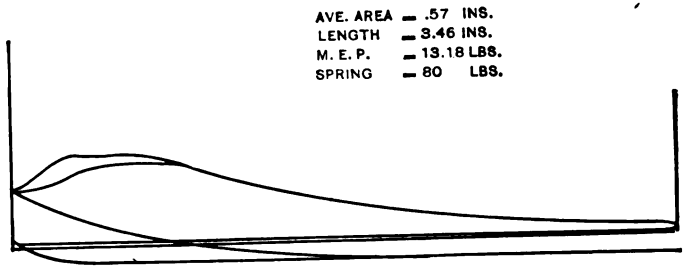
The heat balance may be made from another standpoint, and more in detail, by adding the per cent. equivalent of the engine

CD BY USE OF A PRONY BRAKE.

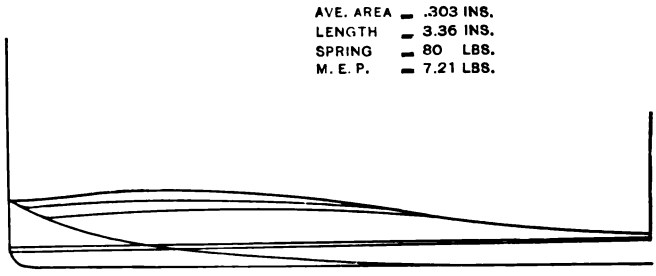
British Thermal Units.

	Absorbed by Jacket.			Equivalent to			
	Per Test.	Per Hour.	In Per Cent. of Amount Supplied.	I. H. P. in Per Cent. of Amount Supplied.	Exhaust and Radiation in Per Cent. of Amount Supplied, Disregarding Heat Equivalent of Friction of Engine.	Exhaust and Radiation in Per Cent. of Amount Supplied. Including Friction of Engine.	B. H. P. in Per Cent. of Amount Supplied.
	29	30	31	32	33	34	35
4.83	178653.48	267980.21	57.61	10.17	32.16	42.39	.....
9.12	271293.83	361725.10	53.64	18.30	28.06	34.51	11.85
0.48	322410.47	429880.63	37.01	25.42	37.57	42.48	20.51
2.12	331610.84	442147.79	32.11	26.58	41.31	45.09	22.80
0.35	358988.16	478650.88	29.62	25.88	44.50	47.82	22.56

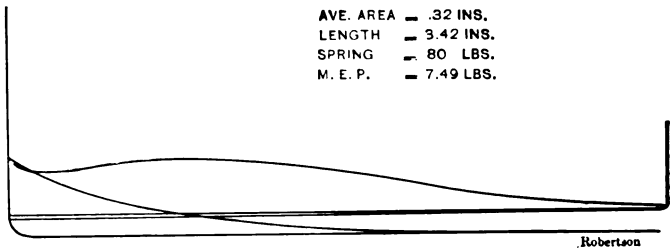
more in detail, by adding the per cent. equivalent of the engine



CYLINDER No. 1

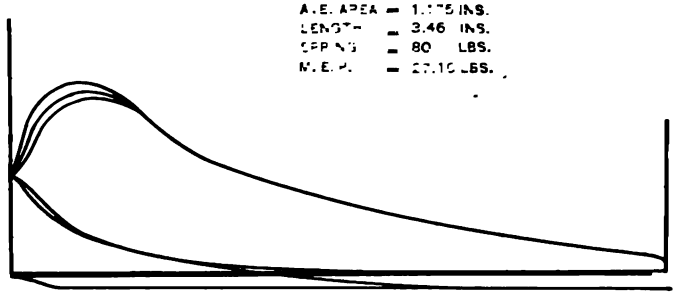


CYLINDER No. 2

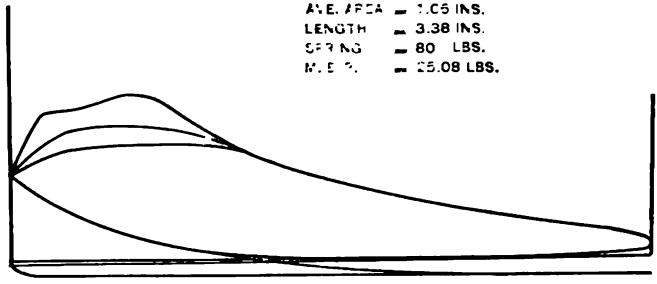


CYLINDER No. 3

FIG. 217.



CYLINDER No. 1



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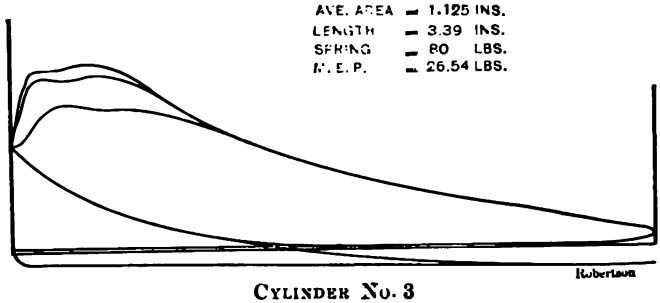
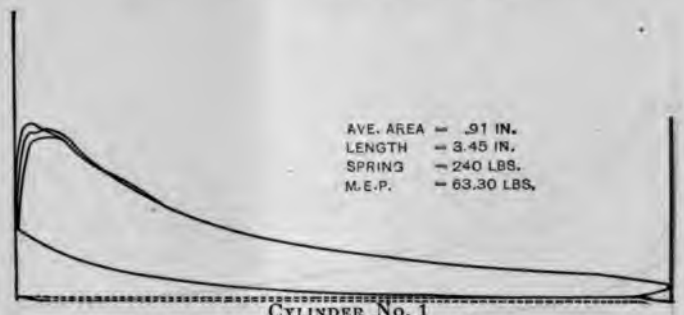
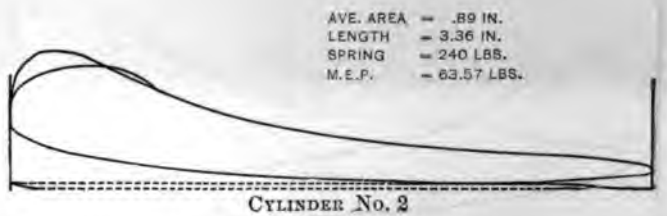


CYLINDER No. 3

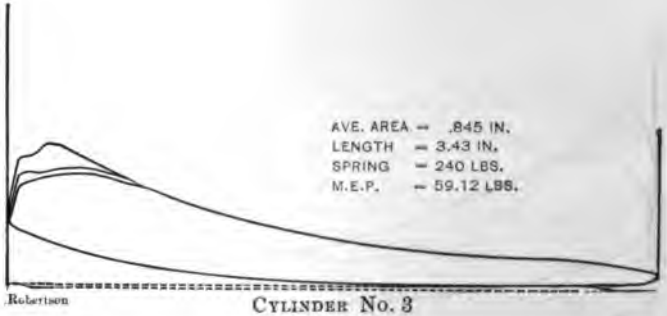
FIG. 218.



CYLINDER No. 1



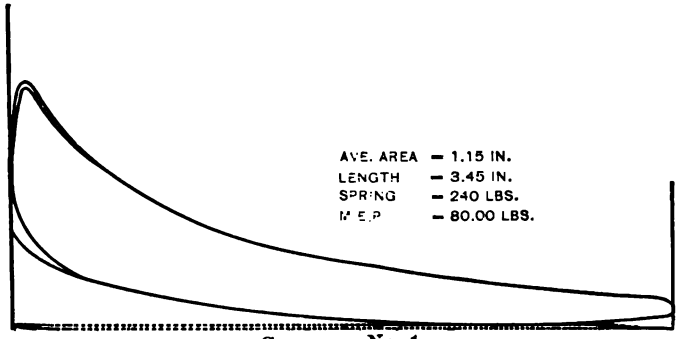
CYLINDER No. 2



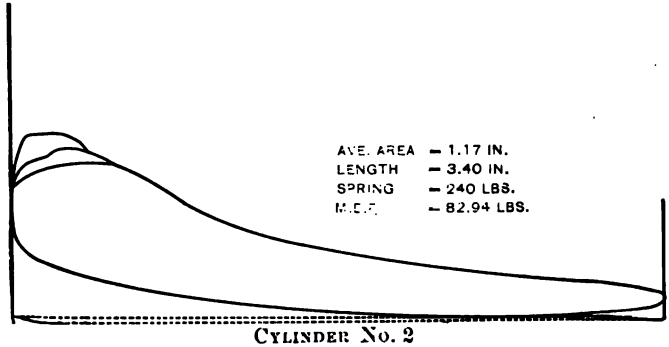
Robertson

CYLINDER No. 3

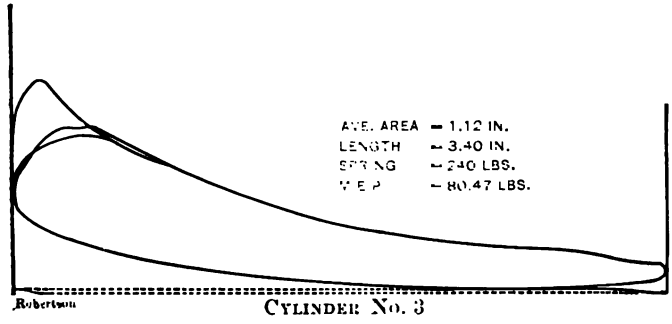
FIG. 219.



CYLINDER No. 1

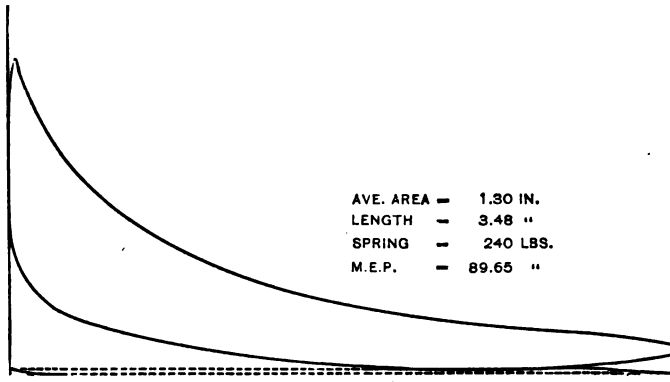


CYLINDER No. 2

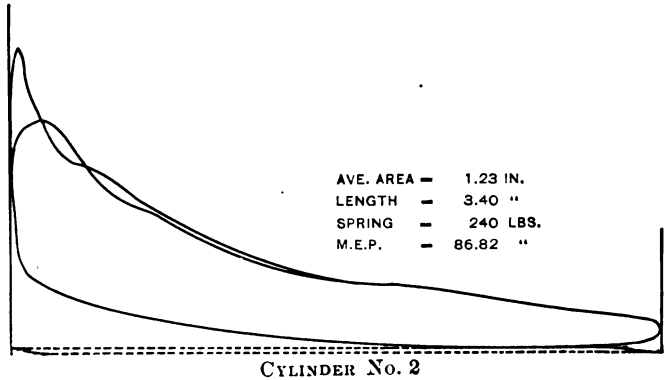


CYLINDER No. 3

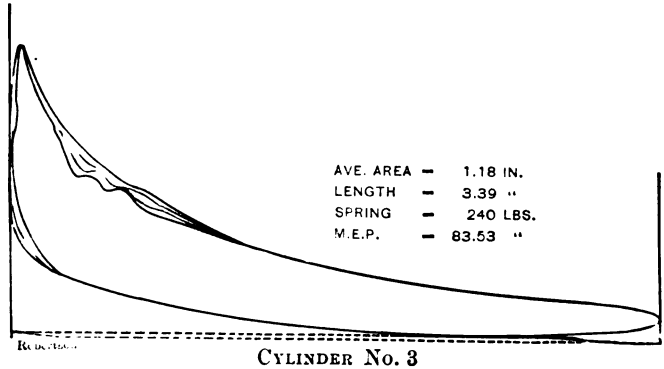
FIG. 220.



CYLINDER No. 1

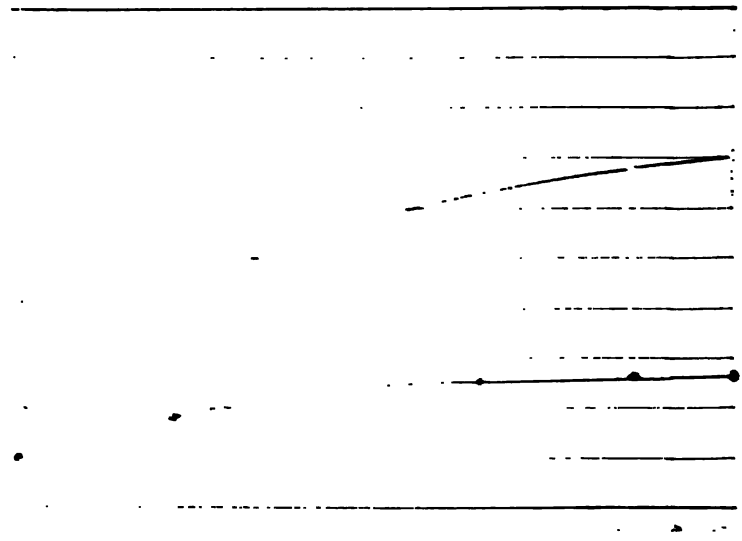


CYLINDER No. 2



CYLINDER No. 3

FIG. 221.



friction to the amount exhausted and radiated. This is well shown in Fig. 223, where the exhaust and radiation area is not bounded by the indicated horse-power, but by the brake horse-power curve, thus including the friction of the engine. This per cent. of friction area represents a double operation: first, the transformation of heat into work on the piston, and second, the reconversions of this energy into heat. This method of analysis

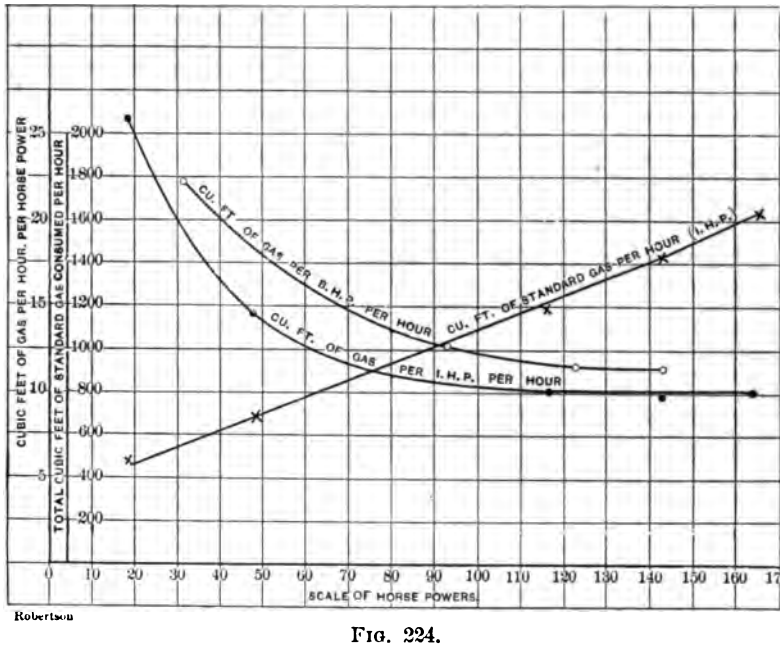

CUBIC FEET OF GAS PER HOUR, PER HORSE POWER
TOTAL CUBIC FEET OF STANDARD GAS CONSUMED PER HOUR
CU. FT. OF GAS PER B.H.P. PER HOUR
CU. FT. OF STANDARD GAS PER HOUR (I.H.P.)
CU. FT. OF GAS PER I.H.P. PER HOUR
SCALE OF HORSE POWERS.
Robertson

FIG. 224.

increases the figures for exhaust and radiation by the amount of the friction of the engine.

When divided in this way and at zero brake horse-power, about 58 per cent. of the heat given to the engine is absorbed by the jacket, and 42 per cent. is exhausted. When the horse-power is maximum (164 indicated or 142 brake), about 23 per cent. is realized in work at the fly-wheel, 29 per cent. goes to the jacket, and 48 per cent. is lost by radiation and exhaust.

The chart illustrates very nicely the well-known fact that a decrease in jacket produces an increase in exhaust loss.

23. In Fig. 224, the straight line shows the gas consumed per hour, plotted against the indicated horse-power. This illustrates, approximately, the Willans law, pointed out in the previous paper.

It should be said, however, that a slight curve would fit the points better than does the straight line. The two curves show the relations of gas per horse-power per hour and horse-power. The upper is in terms of brake horse-power, and the lower in terms of indicated horse-power.

Fig. 225 shows the curves for the various efficiencies, and also that for frictional horse-power. The curves for thermal effi-

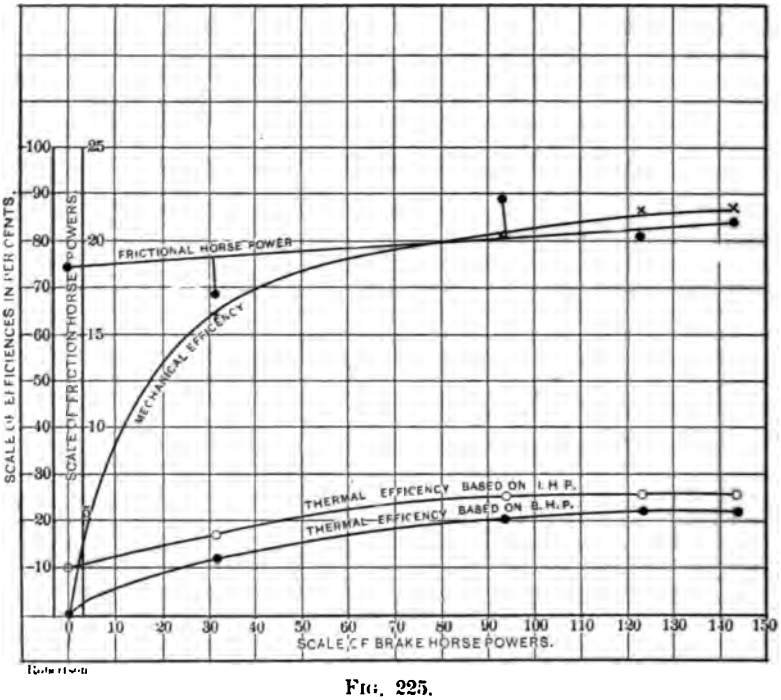

SCALE OF EFFICIENCIES IN PER CENTS.
SCALE OF FRICTION HORSE POWERS.
FRICTIONAL HORSE POWER
MECHANICAL EFFICACY
THERMAL EFFICENCY BASED ON I.H.P.
THERMAL EFFICENCY BASED ON B.H.P.
SCALE OF BRAKE HORSE POWERS.

FIG. 225.

ciency, based on brake and indicated horse-power, show, as a maximum, 22.56 and 25.8 per cent. respectively.

24. The points for frictional horse-power show some variation from the line drawn to represent them, but, on the whole, they may be regarded as very satisfactory. In the experience of the author, it has been found to be very difficult to secure entirely consistent data for the frictional horse-power of an engine. The curve shows, on the whole, a slight increase of friction with increase of load. The average friction of the five tests in horse-power is 19.9. The equation of this line, in term of brake horse-power, is expressed by the following:

F. H. P. = $(\text{F. H. P.})_0 + C \times$ B. H. P., in which
F. H. P. = frictional horse-power.
$(\text{F. H. P.})_0$ = frictional horse-power at zero brake horse-power.
C = a constant.

By substituting the value of constants, the equation becomes F. H. P. = 18.57 + .017 B. H. P.

The fact that the frictional horse-power is practically constant means, of course, that the mechanical efficiency should show an increase with an increase of horse-power. This is very nicely illustrated by the curves for this factor, the data of which were obtained by dividing the brake horse-power by the indicated. The highest value (87 per cent.) would be considered a fair one for a steam engine and is certainly very good for a gas engine.

Appendix I.

Tuning-Fork Chronograph.

25. Ordinarily, the speed of the engine was determined by use of hand-speed indicators and by means of two revolution counters driven continuously by the engine. These methods gave satisfactory indications of the speed at which the engine was operating, but did not suffice to show fluctuations due to sudden changes in the load. In order to make determinations of such fluctuations a tuning-fork chronograph was designed and constructed.

This apparatus consisted essentially of a metal drum about $4\frac{3}{8}$ inches in diameter, with a spindle at one end, terminating in a point which fitted into the lathe-mark of the engine shaft. On this spindle was a crank which engaged with a hole drilled in the engine shaft, and thus gave motion to the drum. The motion of the drum was transmitted, by means of gearing, to a screw which served to drive a carriage carrying a tuning-fork, in a direction parallel to the axis of the drum. The fork was kept in vibration by an electro-magnet. On one of the prongs of the fork was a pen which vibrated with it, and, by marking on the paper, made a graphic record.

26. Time intervals were also marked by a pen operated by another electro-magnet. A clock placed in a battery circuit, making and breaking the circuit at every vibration of the pendulum, caused the motion of the pen. The entire apparatus was secured to a base which had a sliding fit in a wooden channel.

This channel was supported on levelling screws, so that the instrument could be placed in a level position, and the drum made concentric with the engine shaft. The channel being secured in position, the rest of the apparatus could be connected and disconnected from the engine at will.

27. Paper coated with lampblack was used to secure the records, which were afterward "fixed" by being sprayed with a mixture of alcohol and shellac. Before beginning the test it was found that the rate of vibration of the tuning-fork was about 248.3 per second, and that it was practically constant.

Records were taken with the engine under different loads, part with the engine under a brake load and a dynamo load combined, and part with the engine under a dynamo load alone. In some cases where the brake was employed the load was changed from maximum to minimum as rapidly as possible, and the amount of change of load recorded.

28. For each record an average number of vibrations per revolution was found. See Fig. 226, which is a reproduction from a section taken out of the complete record. Here the engine motion is toward the left, and the average vibration number found was 57. This card is not in its best form for determining the speed variation. By laying it over a piece of paper and pricking through every 57th vibration the curve *mo*, Fig. 227, was determined. From *m* to *p* and from *q* to *r* the engine is losing speed, and from *p* to *q* and *r* to *o* it is gaining. This same curve (*mo*) may be seen, in part at least, without pricking it through on another sheet of paper, by so holding the sheet (Fig. 226) that the eye is in nearly the same plane as the paper, and viewing it at different angles until the line of the crests of the waves of each successive revolution appears as a smooth curve across the paper.

29. The nearer the curve *mo*, Fig. 227, approaches a straight line the more nearly constant is the speed. When the angle of the tangents of this curve increases from zero, the speed of the engine decreases. As the curve is regular, the speed is smoothly variable. With the angle of the tangent less than 90 degrees, the speed increases when the curve is concave downward and decreases when the curve is concave upward. With the angle of tangents greater than 90 degrees, these statements hold, but in a reverse order. The inclination of the tangents of the curve to the axis is a measure of the speed, and is easily expressed in

Fig. 226.

revolutions per minute. For curve *mo*, tangents were drawn at every fifth revolution and the angle measured.

30. The manner of determining the revolutions per minute for successive revolutions from the tangents to the curve *mo* was as follows: The fraction or more of a revolution made in 57 vibrations or $\frac{57}{248.3}$ of a second $= \frac{c \pm c'}{c}$. (See Fig. 227.) The number of revolutions made, divided by the time of making them, will equal the revolutions in a unit of time (1 second).

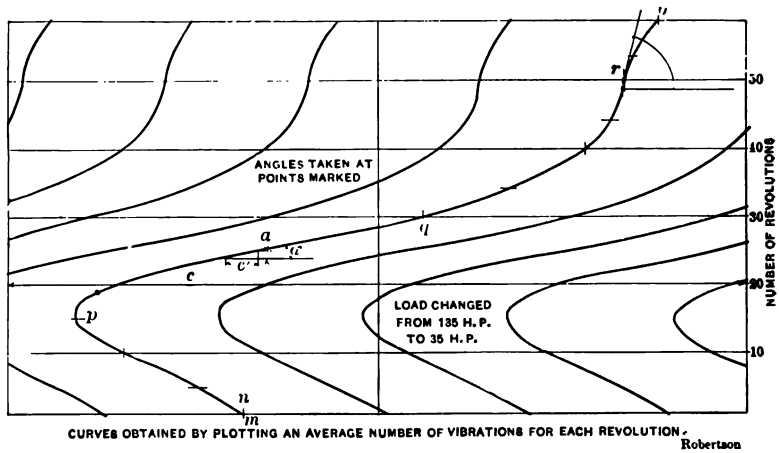


FIG. 227.

$$\frac{c \pm c'}{T}$$

The revolutions per second, , multiplied by 60, will equal the revolutions per minute; or, expressed algebraically,

$$\text{Revolutions per minute} = 60 \frac{c \pm c'}{cT},$$

in which

c (constant) = Circumference of drum = 13.5".

c' (variable) = Distance engine gains or loses per revolution $= \frac{a}{\tan \alpha}$.

a (constant) = Space between successive revolutions = $\frac{1}{8}$".

T = Time for 57 vibrations = $\frac{57}{248.3}$ of a second.

α = Angle of the tangent of the curve *mo*, at any point, to the axis c.

By reducing,

$$\text{Revolutions per minute} = 60\,\frac{c \pm c'}{cT} = 60\left(\frac{c \pm \dfrac{a}{\tan \alpha}}{cT}\right)$$

$$= 60\left(\frac{1}{T} \pm \frac{a}{cT \tan \alpha}\right) = 60\left(\frac{248.3}{57} \pm \frac{248.3}{8 \times 13.5 \times 57 \times \tan \alpha}\right)$$

$$= 60\left(4.35 \pm \frac{1}{24.4 \tan \alpha}\right).$$

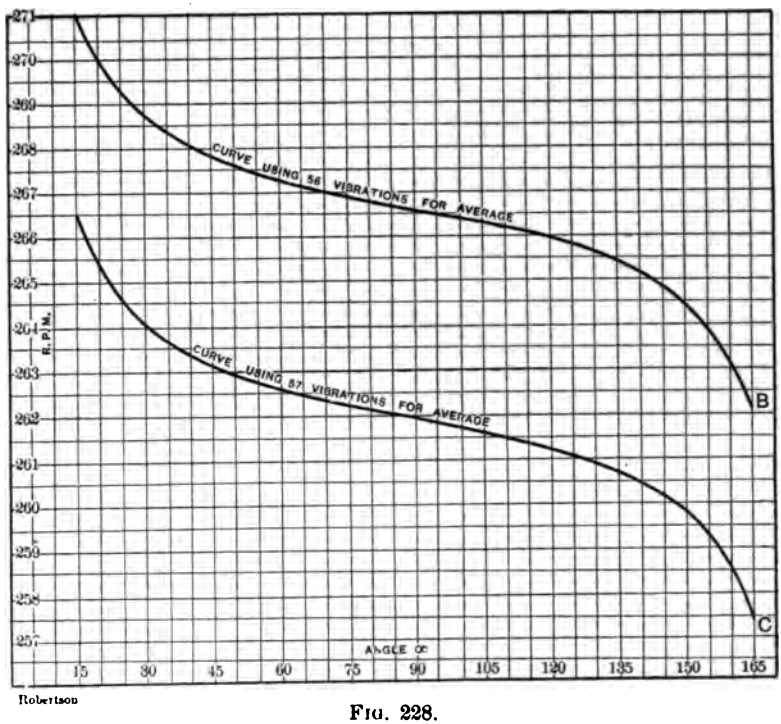


FIG. 228.

In this formula it will be observed that the only variables are revolutions per minute and tan α. The relation of these variables is represented graphically by curves B and C on Fig. 228 for all values of α from 15 degrees to 165 degrees and for two different average numbers of vibrations per revolution.

31. By means of this chart, Fig. 228, the various speeds exhibited by the curve mo of Fig. 227 were easily determined. After being determined, they were plotted graphically as shown by Fig. 229, where it may be seen that at the beginning of the

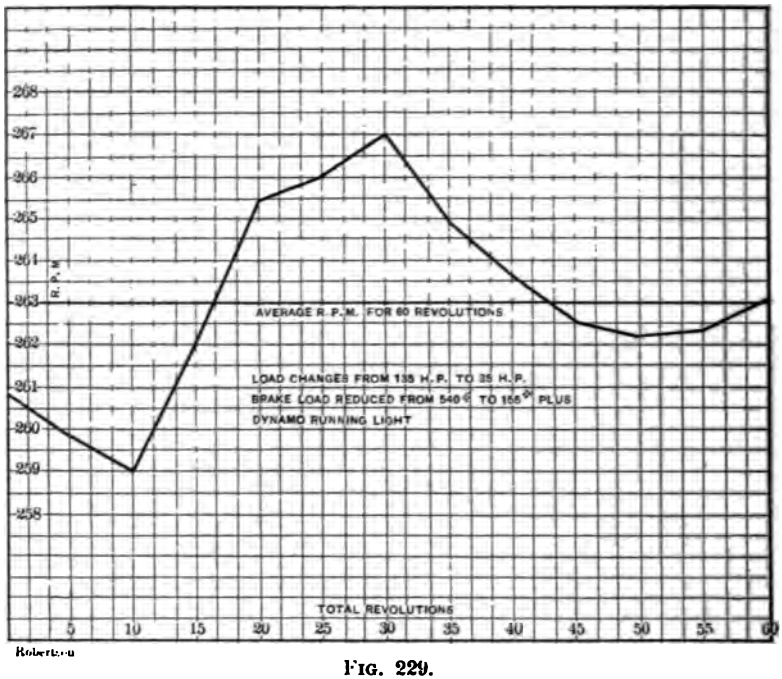


FIG. 229.

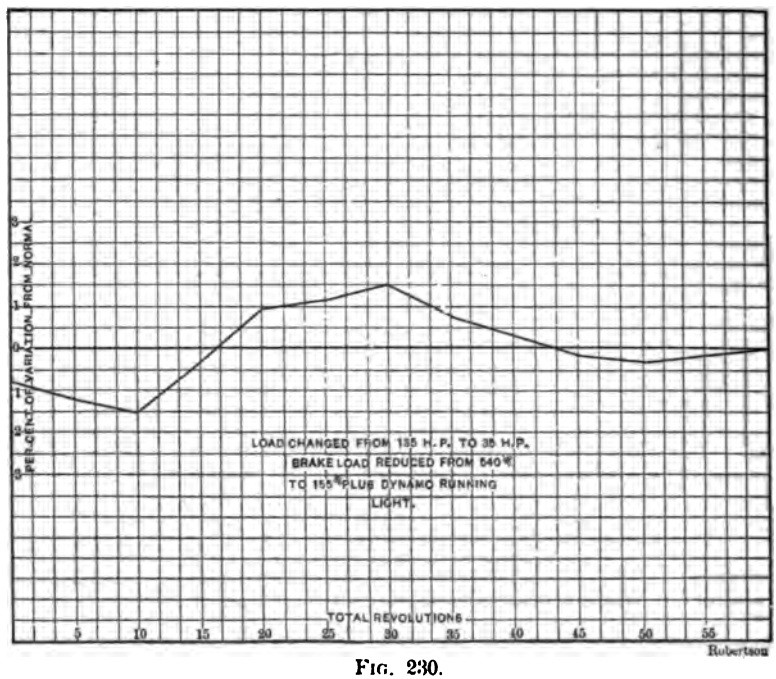

PERCENT OF VARIATION FROM NORMAL
LOAD CHANGED FROM 135 H.P. TO 35 H.P.
BRAKE LOAD REDUCED FROM 540
TO 155 PLUS DYNAMO RUNNING
LIGHT.
TOTAL REVOLUTIONS
5 10 15 20 25 30 35 40 45 50 55
Robertson

FIG. 230.

record the speed was about 260.9 per minute, and that during the next 10 revolutions it dropped to 259, at which point the load was relieved, and in the next 20 revolutions the speed had risen to 267, from which, in 20 revolutions, it swung back to 262.2, from which point another increase, but much less in extent, occurred. The average speed for the 60 revolutions is shown by the horizontal straight line, and is 263. This same speed variation curve, reduced to a percentage basis, is shown in Fig. 230. There it may be seen that the maximum variation was $1\frac{1}{2}$ per

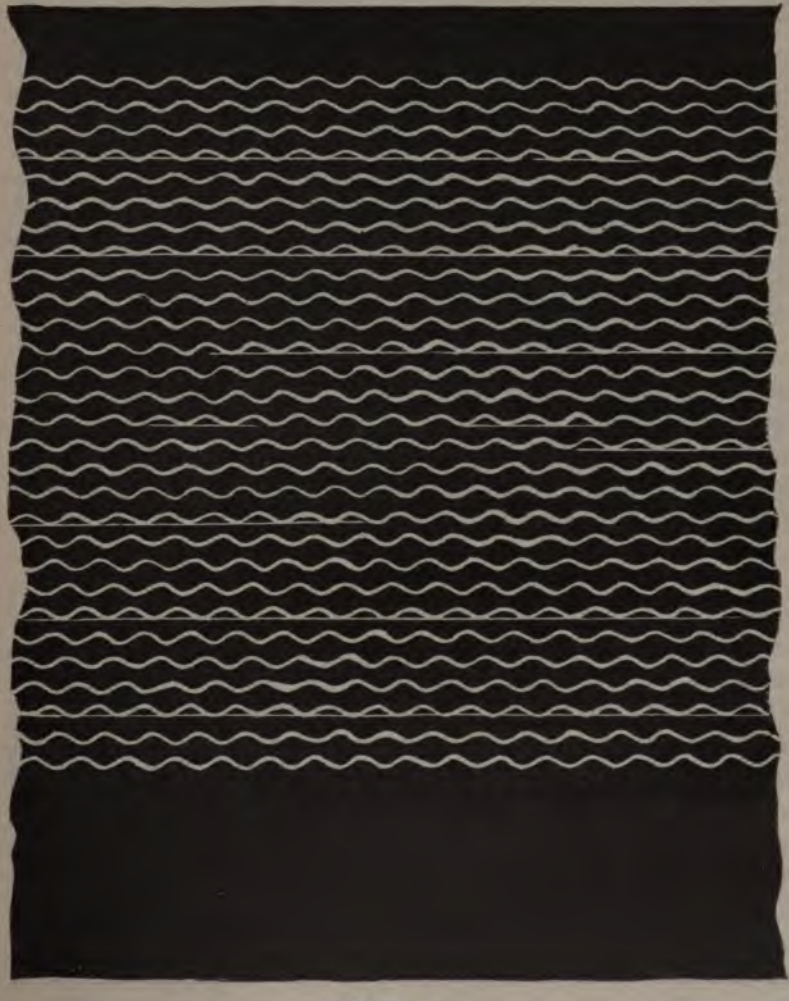


FIG. 231.

cent. below and above normal, or a total variation of 3 per cent.

The record, from which an extract is shown in Fig. 231 was secured when the engine was running under a constant load of about 135 horse-power. A glance across the record shows that the crests of the waves fall into nearly a straight line, and consequently that the speed was practically constant.

32. A summary of the results secured by means of the tuning-fork chronograph may be found in Table V. On the whole, this

TABLE V.

SUMMARY.

Load.	Average R. P. M.	Above Normal.	Below Normal.	Per Cent. above Normal.	Per Cent. below Normal.
Card No. 1, 135 H. P.†	266.05	266.30	265.70	.09	.16
Card No. 2, 135 H. P. to 35 H. P.*	263.	267.	259.	1.5	1.5
Card No. 3, 35 H. P.†	266.4	266.6	266.3	.075	.087
Card No. 4, 55 H. P.†	269.6	269.8	269.35	.075	.094
Card No. 5, 135 H. P. to 35 H. P.*	263.85	266.	261.4	.8	.9

* Variable load. † Constant load.

part of the investigation shows good governing. It may be said that it is not as good as that which is guaranteed for many steam engines. This is unquestionably true, but it may also be said that this governing is better than a great many steam-engine governors in commercial work are giving.

APPENDIX II.

Heating Value of the Gas.

33. The heating value of the gas was determined by means of a Junker calorimeter (Fig. 232). This consists essentially of a small water-jacketed vessel, inside of which gas is burned by means of a Bunsen burner. The gas consumed by the burner was measured by a meter especially provided, which was calibrated before being used. The heat developed was carried away by means of the jacket. The amount of heat thus carried away was determined by measuring the amount of water passing, and its rise of temperature. A copy of the observed and calculated results is shown in Table VI. In all, eleven determinations were made, on

dates extending from May 5th to May 10th. On account of improper conditions, only four of the eleven determinations are reported.

34. In the first test it was attempted to have the temperature of the chimney gases just equal to the temperature of the room.

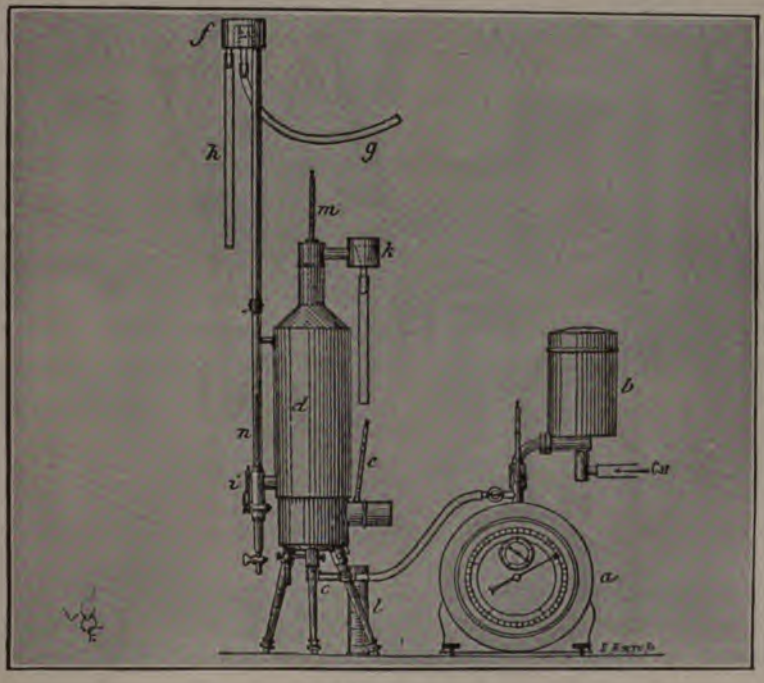


FIG. 232.

This necessitated a high initial temperature of the cooling water, which resulted in its final temperature being considerably above the temperature of the room. This, in turn, gave rise to considerable radiation from the apparatus which thus escaped measurement, and to that extent tended to show a low heating value of the gas. This radiation error was much greater than that due to chimney losses. To make it practically negligible, the initial and final temperatures of the cooling were made to be about an equal number of degrees above and below the temperature of the room.

35. In calculating the results, the amount of cooling water used was determined by multiplying the number of cubic feet of water by the weight of a cubic foot at the temperature at which its

TABLE VI.

SUMMARY OF OBSERVED AND CALCULATED RESULTS FOR DETERMINING HEATING VALUE OF GAS BY MEANS OF A JUNKER CALORIMETER.

No. of Test.	Date of Test.	Rate of Gas, Cu. Ft. per Hour.	Amount of Water, Cu. Ft.	Meter Readings, Cu. Ft.	Differences, Cu. Ft.	Temperature [Cent. Therm.]. Room.	Water. Inlet.	Water. Outlet.	Gas. Meter.	Gas. Chimney.	Pressure of Gas, Inches of Water	Barometer.	B. T. U. Condition of Test.	B. T. U. Standard Condition.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	May 9, 1900	1.81	.3815		1.	23.51	11.87	34.00	22.20	15.74	.2	14.49	941.87	973.14	Initial Temp. of H_2O 11.64°C below atmosphere Temp. Final Temp. of H_2O 10.49°C above atmosphere Temp.
2	May 9, 1900	2.10	.3689		1.	22.63	11.90	34.61	21.79	15.74	.2	14.49	934.09	963.14	Initial Temp. of H_2O 10.73°C below atmosphere Temp. Final Temp. of H_2O 11.98°C above atmosphere Temp.
3	May 9, 1900	2.19	.5070		1.	20.55	11.89	28.74	20.69	15.55	.2	14.49	955.04	981.30	Initial Temp. of H_2O 8.69°C below atmosphere Temp. Final Temp. of H_2O 8.16°C above atmosphere Temp.
4	May 10, 1900	3.54	.7580		1.	18.07	12.235	23.716	18.00	15.00	.4	14.51	944.02	961.82	Initial Temp. of H_2O 5.77°C below atmosphere Temp. Final Temp. of H_2O 5.05°C above atmosphere Temp.
										Total				3879.40	
										Average				969.85	

In all tests .088 lb. of water of combustion was caught.
In all tests the chimney damper was closed.

volume was measured. The pounds of cooling water thus determined were multiplied by the difference in the heat of liquid at its final and initial temperature, which gave the number of British thermal units obtained from the amount of gas burned. Since this gas was at neither standard temperature nor pressure, it was corrected for these two factors, so as to show the number of heat units per cubic foot of gas at 62 degrees Fahrenheit and 14.7 pounds per square-inch pressure. No correction was made for the water of combustion. It is thus seen that the heating values are those for the gas burned to products of combustion and water liquid at temperatures of about 60 degrees Fahrenheit for the first, and 95 degrees for the second. The British thermal units per cubic foot of standard gas (14.7 and 62 degrees F.), as shown by an average of the four determinations, are 969.85, and this value was used in calculating all thermal efficiencies of the engine. Had correction been made for the water of combustion, the heating value would have been lower and the efficiencies correspondingly higher.

APPENDIX III.

Exhaust-gas Temperatures.

36. During the six-hour test the exhaust-gas temperature was measured by means of a LeChatelier pyrometer. This pyrometer consisted essentially of a thermo-electric couple, so placed in the exhaust pipe that the heat would develop an electric current. This current was led by suitable wires to a galvanometer, where it caused a deflection. The thermo-electric joint consists of two wires, one of platinum and the other an alloy of rhodium and platinum. At the point of juncture these two metals are soldered together and the whole encased in a porcelain tube. The general appearance of such a couple is shown in Fig. 233.

On account of the high cost of the material of which this joint was constructed, it was desired that the two parts of the wires be as short as possible, and that the remainder of the circuit be made up of ordinary copper wire. On account of the high temperature, it was necessary to protect the soldered joints where the copper wires were attached. This was done by encasing the whole in a water-jacketed pipe, a section of which is shown in Fig. 234. This whole casing was then screwed into the exhaust

pipe of the centre cylinder, and at a point as shown in the same Fig. 234. The galvanometer was placed on a brick foundation some twenty feet away.

37. The method of the calibration employed was to place the joint in a liquid of known temperature and note the resulting deflection of the galvanometer. Mercury was used as this liquid for

FIG. 233.

temperature up to 676 degrees. The melting point of aluminum (1,157 degrees) was used for the highest point in the calibration. When using mercury an accurate mercurial thermometer was used to observe temperatures. For melting aluminum a special Chaddock burner was used. From previous calibrations it was known that the calibration curve was a straight line. Such a previous calibration curve is shown in Fig. 235.* From knowing this fact, and also because trouble was experienced with the cracking of the protective covering, it was deemed unnecessary

* "The Friction of Brake Shoes under Various Conditions of Pressure, Speed, and Temperature;" a paper before the September, 1900, meeting of the Western Railroad Club by Prof. R. A. Smart.

to calibrate to the highest point at which the joint was to be used.

38. Two calibrations were made, one on May 9th, in which only mercury was used. This calibration is shown by small crosses, Fig. 236. Another calibration was made on May 26th, in which a

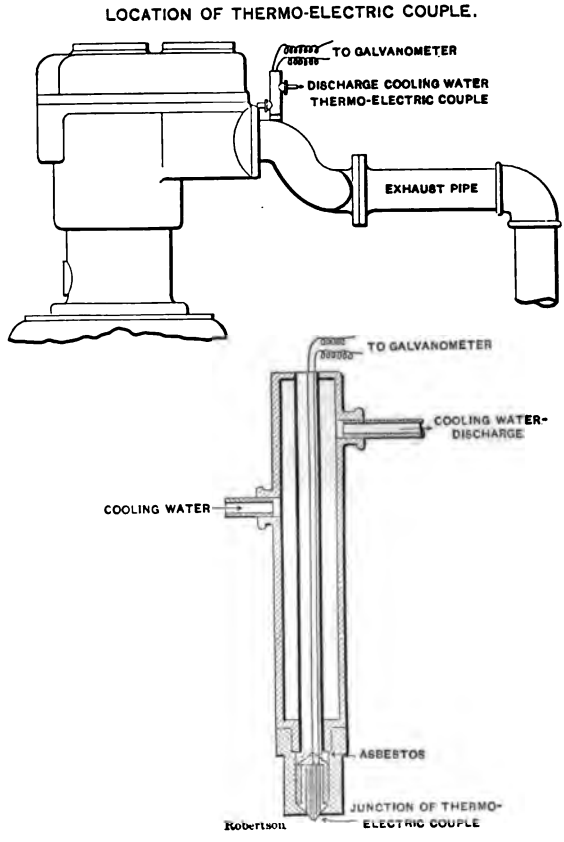


FIG. 234.

greater range of temperature was secured. This is shown on the same plate by the dotted circles. It was from this curve that the exhaust temperatures recorded in Column 17, Table I., were interpolated. There it may be seen that the lowest temperature recorded, 1,410 degrees Fahr., was at 6.15, and that the highest, 1,805 degrees, was at 8.30 to 9.20. These temperatures appear to be rather high—so high, in fact, that the author has examined

other data at hand to see if any confirmation of the above figures could be found.

39. The data secured in the spring of '93, on this same engine, show that the temperature of the exhaust from the centre cylinder, as observed by means of a copper-ball calorimeter, had

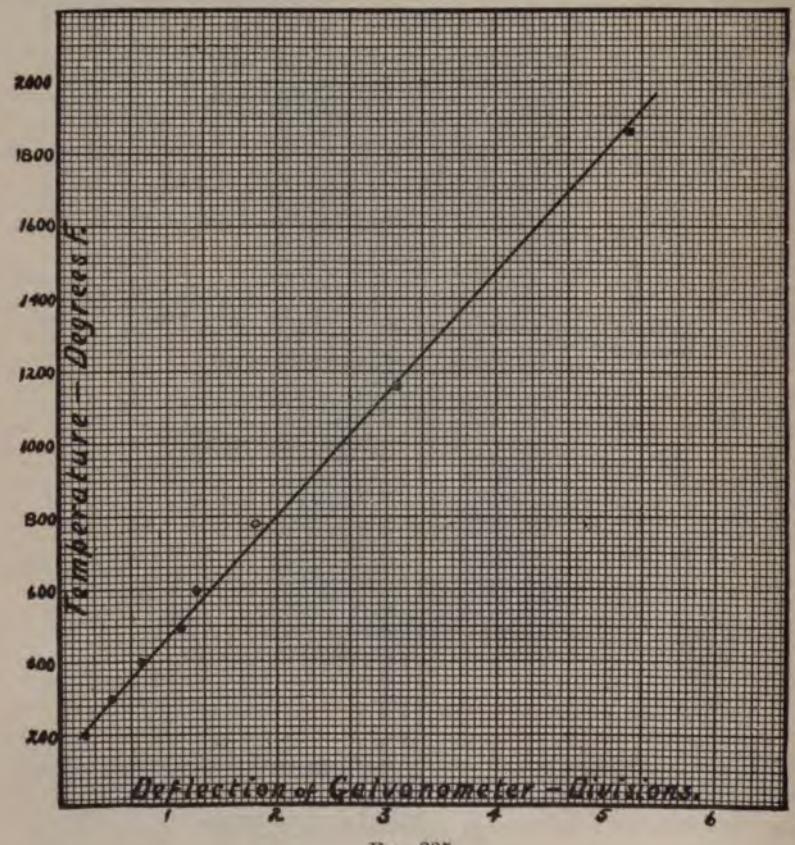


FIG. 235.

an average of about 8 per cent. higher than that of the outside cylinder. (This was taken from an average of ten readings of the left and centre cylinders.) During a test, one week before the one here recorded, an attempt was made to get a check on the thermo-electric joint readings by means of a copper-ball calorimeter. This copper-ball calorimeter had been placed in the exhaust pipe of the left cylinder. The highest temperature observed by it during the test was 1,605 degrees. If this be

multiplied by the factor 1.08 (the previously observed ratio of the temperature of the left and centre cylinder), the result appears to be 1,733 degrees. In view of the fact that no attempt was made to correct for radiation from the copper ball during the

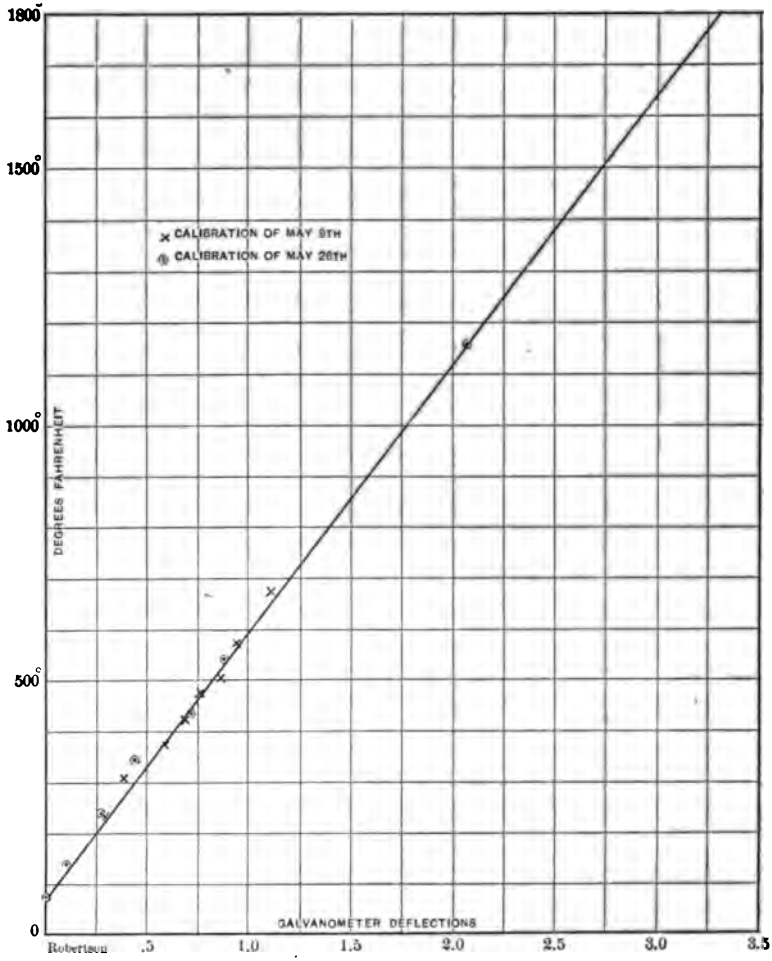


FIG. 236.—CALIBRATION OF THERMO-ELECTRIC JOINT.

time occupied in transferring it from the exhaust pipe to the water cup, it should be expected that the determination made by its use would be somewhat lower than the true temperature. In the light of this data, it was concluded that the thermo-electric joint reading was approximately checked. As remarked

before, the results seem very high, and it was expected that a verification of the work on the exhaust temperature would be made in March of this year. This was prevented by the fact that the engine was not running at that time, on account of the supply of natural gas being shut off.

The results of the thermo-electric joint readings for the test (Col. 17) are shown graphically in Fig. 211. There it may be seen, as might be expected, that the temperature rises with an increase of horse-power. It is of interest, also, to observe the dip in the curve at 6.15, which was caused by the centre cylinder being temporarily out of action, due to the accidental short-circuiting of the igniters by one of the steel hooks on the indicator cords.

Appendix IV.

Observation and Calculation.

40. The following description of observations and calculations applies to the six-hour test while the engine was carrying the regular station load. The data mentioned and the columns referred to may be found in Table I.

During the test, practically all observations were at five-minute intervals. In almost all cases two independent observers were employed. These observers were junior and senior students in mechanical engineering, and all had had special training in such work.

41. Revolutions per minute (Cols. 4, 5, 6, 7, 8, and 9).—The revolutions of the engine were determined by three methods. First, by means of a hand speed indicator; second and third, by means of revolution counters driven from the exhaust valve stems. Since the engine works on the Otto cycle, these revolution counters show just half the revolutions of the engine during the time observed.

42. Heat absorbed by jacket (Cols. 10, 11, and 12).—The thermometers used in determining the initial and final temperature of the jacket cooling water were inserted in the pipes just before and after the cooling water reached the jacket. The weight of the cooling water was determined by running it alternately into barrels placed on platform scales, and so arranged that one could be weighed and emptied while the other was being filled. The amount of heat given to the jacket was not computed for this

test. The method here described was used and the results computed for the series of short tests (paragraph 33).

43. Temperature of engine room (Col. 13).—The temperature of the engine room was determined by means of a thermometer suspended near the intake end of the air-supply pipe to the engine.

44. The temperature of the exhaust (Cols. 14, 15, 16, 17, and 18) was determined by means of an electric pyrometer as described in paragraph 36.

45. Proportion of gas to air (Cols. 19 and 20).—The proportion of gas to air was assumed to be that shown by the mixing valves of the engine. This part of the engine is very accurately machined, so that the pointers on the gas and air valves, respectively, indicate the relative areas of the air and gas admission ports. No attempt was made to determine whether or not the proportion thus shown was accurate, but, before beginning the test, the best proportion of gas to air in terms of the setting of the mixing valves was found experimentally. The method of procedure was to put the engine under constant brake load, and, with a given setting of the air and gas valves, to determine the amount of gas consumed for a given time. Then, at the same brake load, another proportion was tried. In this way the best proportion of gas and air was accurately determined, in terms of the setting of the mixing valve, and is shown in Cols. 19 and 20.

46. Temperature of the mixture of gas and air (Col. 21).—Temperature of the mixture of gas and air was determined by inserting the bulb of a thermometer directly into the distribution pipe which runs across the front of the engine and which serves to distribute the mixture from the mixing valves to each of the cylinders.

47. Gas measurement (Cols. 22 to 26).—The natural gas used as fuel was measured by means of a Westinghouse wet gas meter of 5,000 cubic feet per hour capacity. This meter was tested before beginning the tests and found to be exact. The pressure and temperature of the gas were determined just as they entered the meter, the one by means of a mercury U tube, and the other by means of a thermometer the bulb of which was inserted directly into the gas supply main.

48. Governor position (Col. 27).—The positions of the governor throughout the test were observed by means of a deflectometer

so arranged as to give a multiplied motion of the governor stem. Its readings are merely relative.

49. Indicator cards (Cols. 28 to 34).—Indicator cards were taken by means of special gas-engine indicators, one placed on each cylinder of the engine. In taking cards, the pencil was held against the paper for from 3 to 5 revolutions, in order that a good average might be secured. In planimetering the cards all those diagrams were traced, and an average taken for all of each reading. In this manner the mean effective pressure for each cylinder was determined.

50. Total indicated horse-power (Col. 35).—The following formula was used in calculating the indicated horse-power of the engine:

$$\text{H.-P.} = .00235\ PN;$$

in which

$$.00235 = \text{H.-P. constant} = \frac{LA}{2 \times 33{,}000} = \frac{14 \times 3.1416 \left(\frac{13}{2}\right)^2}{2 \times 12 \times 33{,}000}$$

P = sum of mean effective pressure of the three cylinders.

N = revolutions per minute.

51. Average indicated horse-power (Col. 36).—In order that curves might be plotted, showing the general averages and performances of the plant throughout the test, the more important of the calculated results were averaged for 10-minute periods. These averages for the indicated horse-powers are shown in Col. 38. The method of determining the average values shown in this column was to divide the whole series of observations into a series of 10-minute tests, and take an average of all observations during the 10 minutes. For instance, the average indicated horse-power for the first 10 minutes of the test was at 6.05, and is the average of the indicated horse-powers 86.42, 88.06, and 89.09, the indicated horse-powers as determined at 6.00, 6.05, and 6.10, respectively. This average horse-power was 87.86, and in the same manner were determined all the average indicated horse-powers shown in column 36. This same method of averaging was used in all the readings where the observed quantity was not cumulative, as, for instance, in the gas measurement. For all such observations the actual quantity measured was put down opposite the time, midway between the beginning and the ending of the measurement in question.

52. Dynamo horse-power (Cols. 37 to 39).—The output of the dynamo in kilowatts was determined by the use of accurately calibrated apparatus. In all cases two instruments were used for each observation, in order that a check might be had. Kilowatts resulting from these observations are given in Col. 37. From them was calculated the output in electrical horse-power (Col. 38). From previous tests on the dynamo its efficiency was known. By dividing the items of Col. 38 by this efficiency the total input of the generator or the brake horse-power of the engine was determined (Col. 39). In making this calculation no allowance was made for losses due to slippage of the belt.

53. Frictional horse-power of engine (Col. 40).—This item was determined by subtracting the brake horse-power (Col. 39) from the indicated horse-power (Col. 36).

54. Mechanical efficiency of engine (Col. 41).—This item was determined by dividing the brake horse-power (Col. 39) by the indicated horse-power (Col. 36) and multiplying by 100.

55. Standard gas per horse-power (Cols. 43 to 45).—The standard gas per indicated horse-power hour, per brake horse-power hour, and per electrical horse-power hour, was determined by dividing these corresponding horse-power hours into six times the standard gas per 10 minutes (Col. 26).

56. The thermal efficiencies (Cols. 46 and 47).—The thermal efficiencies of the engine and of the plant are shown in Cols. 46 and 47, respectively. These efficiencies were calculated by dividing the heat equivalent of a horse-power hour by the British thermal units in the gas consumed per brake horse-power hour and per electrical horse-power hour, the heating value of the gas being taken as 969.85. (See paragraph 33.)

APPENDIX V.

Miscellaneous Apparatus.

57. The indicators used in the test were all especially constructed for gas-engine work. That on the cylinder No. 1 was of the Crosby, and those on the cylinders Nos. 2 and 3 of the Tabor make. The springs were changed from time to time to adapt them to changes of pressure due to changes in the load.

58. The indicator rig consisted of a small set of three cranks, turned from a solid piece of steel and attached by means of a

cap to the end of the engine shaft. Connecting rods, steel wire, and short pieces of indicator cords serve to transmit the motion over light brass pulleys to the corresponding indicators. The springs principally used during the tests were calibrated and were found to be correct.

59. The gas was measured by means of a Westinghouse wet gas meter that had a capacity of 5,000 cubic feet per hour, and when tested, before beginning the series of tests, was found to be correct.

60. All thermometers used in the test were of the sort in which the scale is engraved on the glass stem; all were calibrated after the test. All used the Fahrenheit scale except those in connection with the gas calorimeter, which were graduated according to the Centigrade system. The electrical instruments used were:

61. A Thompson A. C. wattmeter, a Weston wattmeter, a Thompson ammeter, and a Whitney voltmeter. All were carefully calibrated.

DISCUSSION.

Mr. F. A. Scheffler.—Will the author please explain the great variation, and which seems to me to be a most important one, in the frictional horse-power of the engine as given in Col. 40 of Table I?

The first tabulated result is 31.01 horse-power, frictional, with total indicated horse-power 87.86 (Col. 36). The final reading is 22.88 horse-power (frictional), with total 53.69 horse-power (Col. 36).

Midway in the table the total horse-power reading of 134.46 (Col. 36) is given, while the corresponding frictional load is only 14.72 (Col. 40).

Analyzing the first and final readings above referred to, there is a variation in friction of engine of 30 per cent., or with the higher load the friction is 9 horse-power more than it is with the lighter load. But when the load is still further increased from 87.86 horse-power to 134.46 horse-power the friction is 17 horse-power *less*.

This variation in the relation of load to friction seems to run through the readings, and I do not understand how reliable efficiencies can be calculated from these results.

*Mr. C. H. Robertson.**—In reply to Mr. Scheffler's question about the variation in the frictional horse-power, I would say that it has been my experience that it is very difficult to secure entirely consistent data in regard to the friction of an engine, either gas or steam. I presume that I have seen 100 tests on steam engines in regard to this particular point, and I have always found considerable irregularity.

I think this is due mainly to two causes. The frictional horse-power is gotten as a difference between the indicated and the delivered horse-power. Any slight error in determining either or both of these would appear as a variation in the frictional horse-power, and since compared to either of these it is very small, the variation might be proportionately very large.

The other cause for variation in the figures would be the variation in the friction of the engine due to changes of load or of lubrication. An examination of the column mentioned or of the curve for frictional horse-power (Fig. 211) shows that there were no very sudden fluctuations, as would be expected if there had been any considerable error in the determinations.

On the other hand, the data show a quite regular variation, due probably to changes of load and of lubrication. The results are as consistent as are those generally gotten from steam-engine tests, and indeed those shown by Fig. 225 are more so. It is believed by the author that the power determinations are as accurate as those made in steam-engine testing.

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* Author's closure, under the Rules.

No. 896.*

AN IMPROVED TYPE OF INGOT-HEATING FURNACE.

BY F. H. DANIELS, N. E. BOSTON, MASS.
Member of the Society.

1. In the process of reducing steel ingots to a form suitable for further use in the manufacture of wire, etc., no operation is of greater importance than that of bringing the ingot to a proper heat for rolling. For this purpose a number of forms of heating apparatus have been devised. The earliest, and one which, on account of its many excellent features, still remains in considerable favor, was known as the "Soaking Pit." While it is not the function of this paper to describe in detail this arrangement, nor some others which have been devised for a similar purpose, a few general remarks regarding them will not be out of place.

2. The soaking pit then, as generally used, consists, as the name implies, of a chamber into which the ingots are charged vertically from the top, and from which they are later removed in the same manner. This form of furnace is also supplied with regenerative chambers and their concomitant accessories. The introduction of the regenerative principle involves not only a large first cost, including a number of expensive flues, but, on account of the somewhat complicated system of valves, etc., the expense of maintenance is very considerable. As previously noted, in an arrangement of this sort, the ingots are charged and discharged from the top, the operation necessitating the removal of the cover of the pit every time an ingot is introduced or removed. A great amount of heat is therefore allowed to go to waste during this interval.

3. Next in the order of development comes the horizontal heating furnace. This consists of a long narrow passage with a bridge and combustion chamber at one end, the other end being open and provided with a sliding door. This furnace may be direct fired, or may use gas furnished from an outside source, as desired. Into the open end of this furnace, the ingots, after being turned to a horizontal

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

position, are pushed, one by one, generally by means of a hydraulic apparatus. As they approach the combustion chamber they gradually become heated to the required temperature. Here they are removed through an opening in the top of the furnace. To facilitate the pushing operation, the furnace is provided with two water pipes laid longitudinally in the bottom, on which the ingots rest during their passage. This furnace is compact, and, comparatively speaking, may be cheaply constructed and maintained. It possesses, however, certain disadvantages. First, if the ingot is not entirely solidified inside, upon turning it down to a horizontal position the molten metal may break through the thin crust at the top and run out. Second, while passing through the furnace the ingots are of necessity packed closely together side by side; consequently, the upper side alone is subjected to the direct heat of the burning gases. On the other hand, if the ingots approaching the fire box become welded together on account of excessive heat, as sometimes happens through careless heating, they are particularly difficult to separate.

4. A consideration of the inherent defects of the two methods of heating ingots just outlined has led to the development and construction of the vertical heating furnace, and later to its most recent adjunct, the electrical pusher. To describe this latest type of furnace in detail, and to disclose its method of operation, is the specific purpose of this paper.

5. In the accompanying cuts, Figs. 238, 239, 240, and 241 show respectively a semi-sectional plan and a sectional elevation of the furnace as arranged for direct firing. Fig. 242 shows an elevation of the charging end, and Fig. 243 a semi-sectional elevation of the firing end. Figs. 244, 245, 246, and 247 show a semi-sectional plan and sectional elevation of the furnace as arranged for firing with gas from an outside source; Figs. 248 and 249 end elevations of same.

6. The main body and the combustion chambers of the furnace are constructed of fire brick as is usual. Raised from the floor of the furnace, which, as may be noticed from Fig. 240, slopes gradually from each end toward the opening A, is a fire-brick wall. The latter carries a heavy wrought-iron pipe B, in which water is continually circulating. Two pipes may be used so as to give more of an incline to the ingots if deemed necessary. At the firing end of the furnace is a pit C filled with sand, which produces a fluid and free running slag, serving also as a hot bed for the removal of cold spot on the base of the ingot due to contact with pipe B.

7. In the side walls of the furnace the pipes DD are introduced

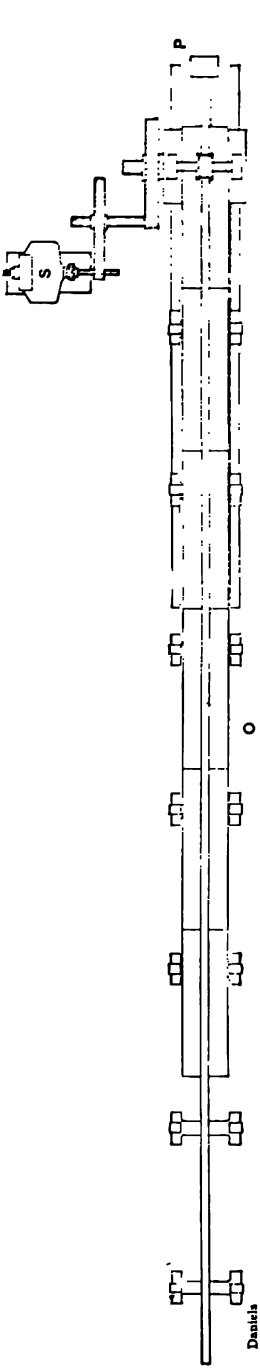


Fig. 228.

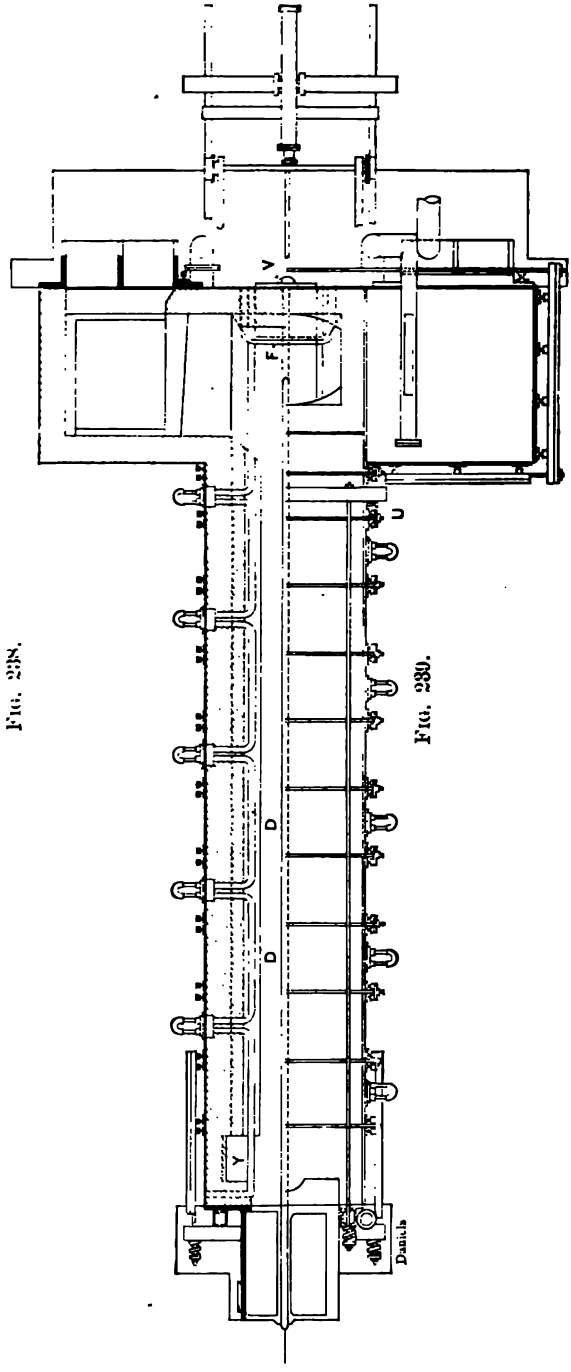


Fig. 230.

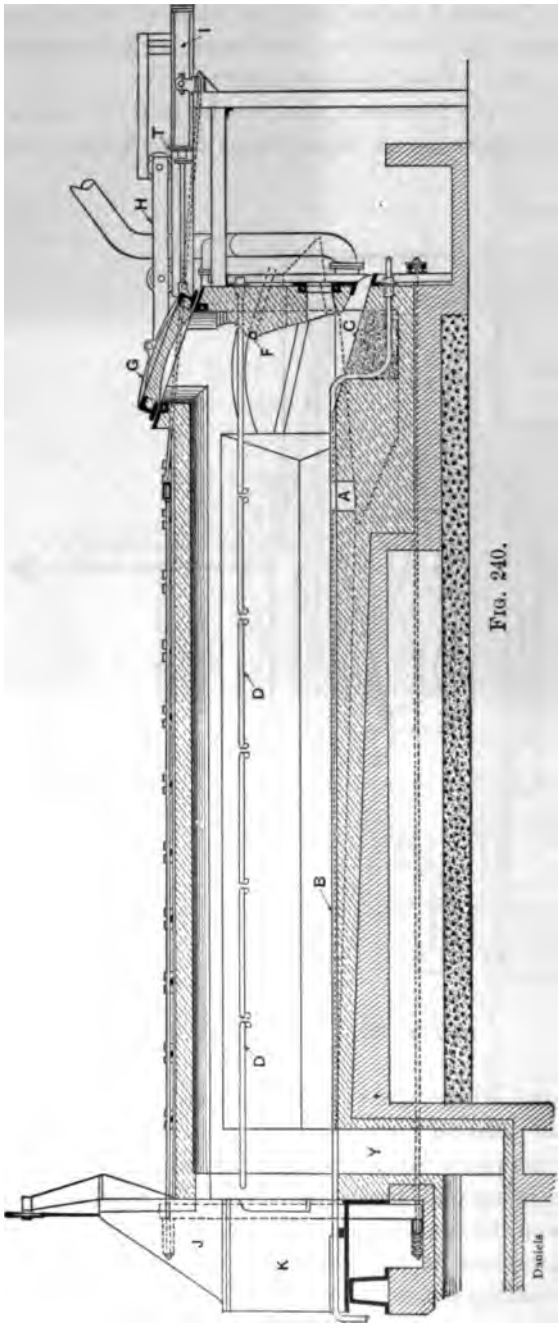


FIG. 240.

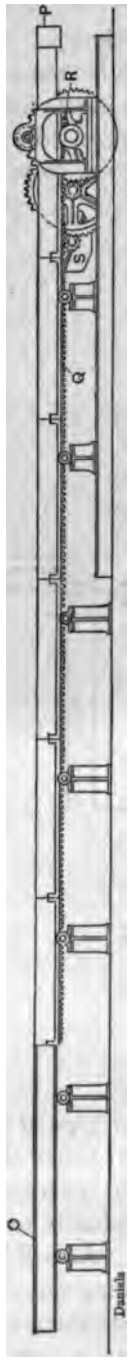


FIG. 241.

as shown. These are inserted in sections, the ends of which are firmly clamped outside of the furnace, so as to secure a rigid support for ingots which lean against them, as later described.

8. At the firing end of the furnace a pipe *F* is let into the wall as shown, to serve as a support for an ingot about to be withdrawn.

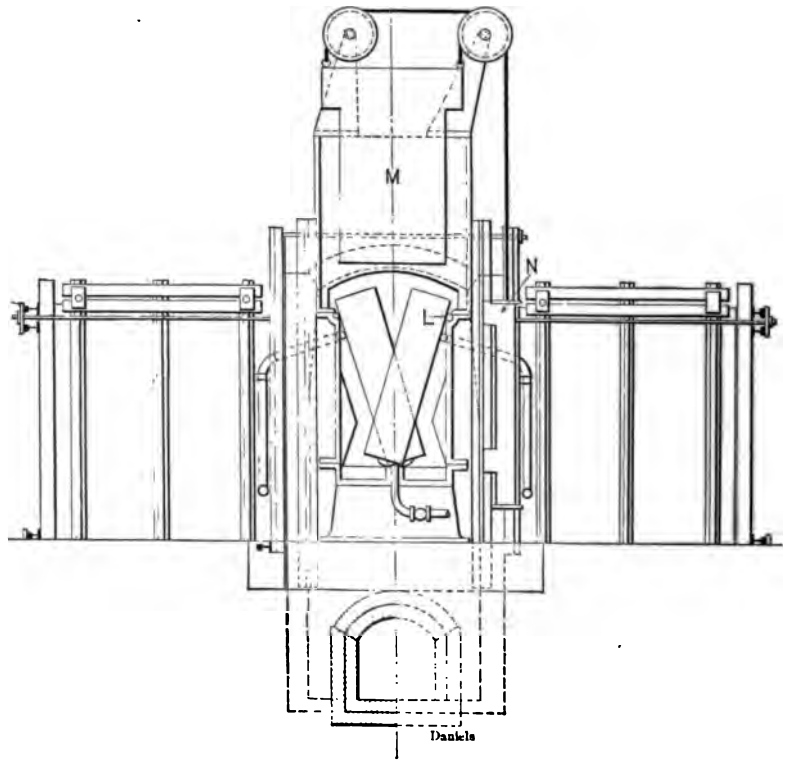


FIG. 242.

The type of fire box and bridge, and the arrangement of blast pipes, are clearly shown, and need no further explanation.

9. Directly above the point where the ingot, having been pushed gradually toward the firing end, must finally rest, is placed a cover *G*. As will be noted on the drawings, this cover carried on truck *H*, rolling on rails *T*, is inclined to the plane of motion, thereby obviating the necessity of lifting before uncovering the opening as is the usual pit practice. The operation of opening and closing the cover

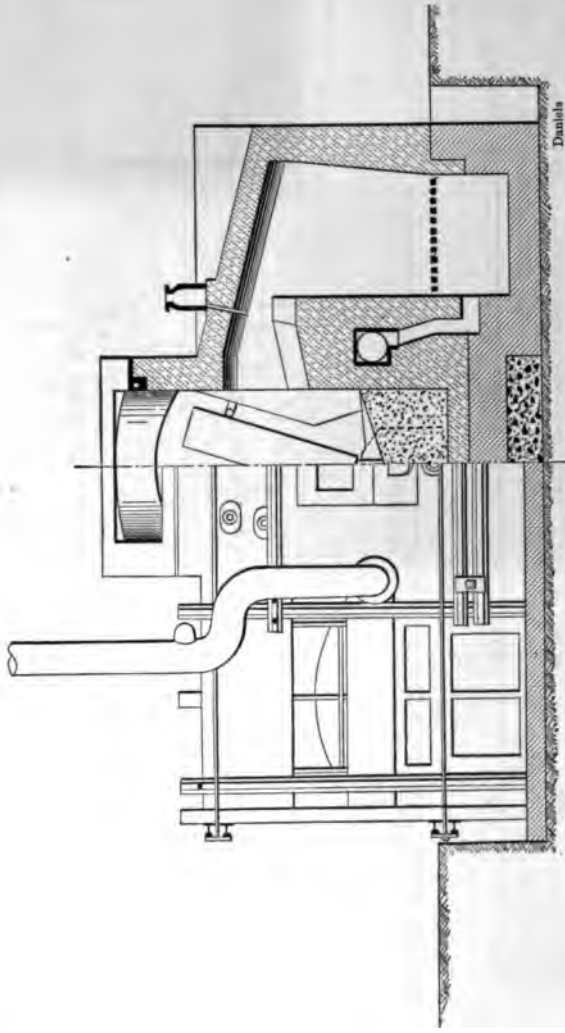


FIG. 243.

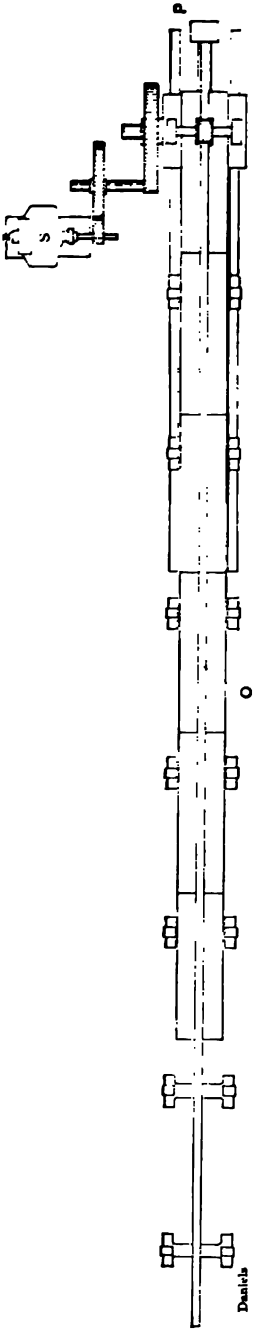


FIG. 244.

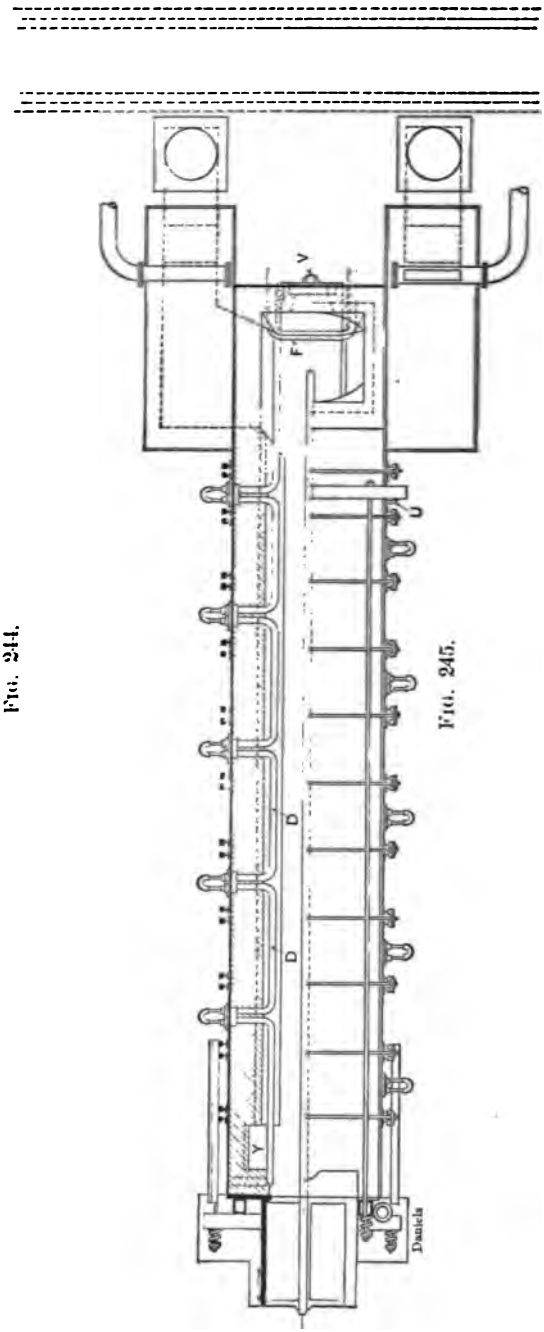


FIG. 245.

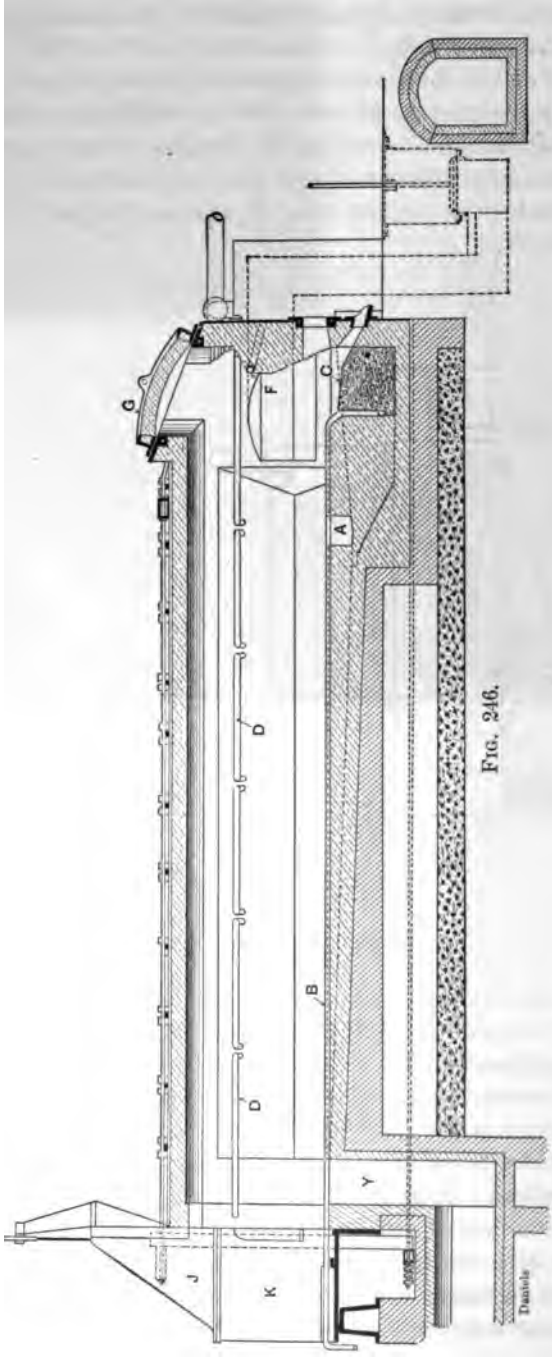


FIG. 246.

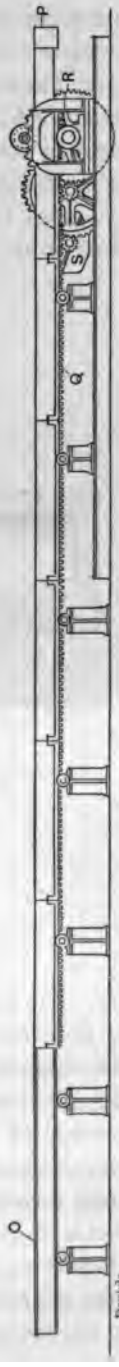


FIG. 247.

is performed by means of the pneumatic cylinder *I*, the piston rod of which is directly attached to the cover as depicted in Fig. 240.

10. The charging end of the furnace is provided with projecting castings *JK*, serving the purpose of a receiver in which ingots are placed in proper position before entering the furnace. The upper casting *J* carries a pair of brackets and rope sheaves; over these pass wire ropes from which is suspended door *M*, operated rapidly by means of air cylinder *N*.

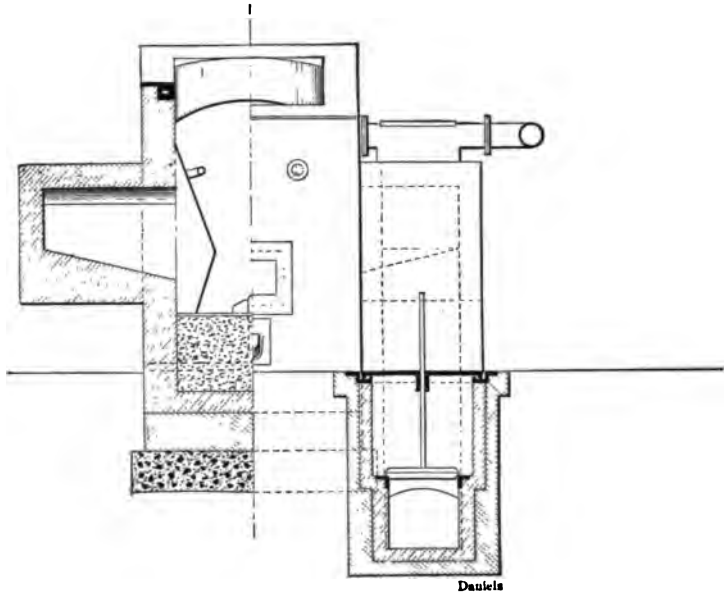


FIG. 248.

11. The gases escape through the flues *OO*, which are so arranged that the draft will be equal on both sides of the furnace. If desired, these flues may contain devices for heating the air blast.

12. The most interesting and novel feature in connection with the operation of the furnace is the pusher. In previous arrangements hydraulic pushers have been used; these are, however, open to several serious objections. It has been found impracticable to construct a single-stroke pusher of sufficient length to charge a furnace of this type, and as with the multiple-stroke pusher the length of stroke is limited, it is necessary when running the pushing head far into the furnace to take a number of successive "hitches"—that is,

the plunger after making a stroke must be run back and a fresh hold taken on the pushing bar by means of a clutch. The process is consequently very slow, and the door of the furnace must remain open a long time. With the high pressure necessary for handling large ingots, say 12 x 12 and above, considerable trouble is experienced in keeping the hydraulic connections tight and in good repair.

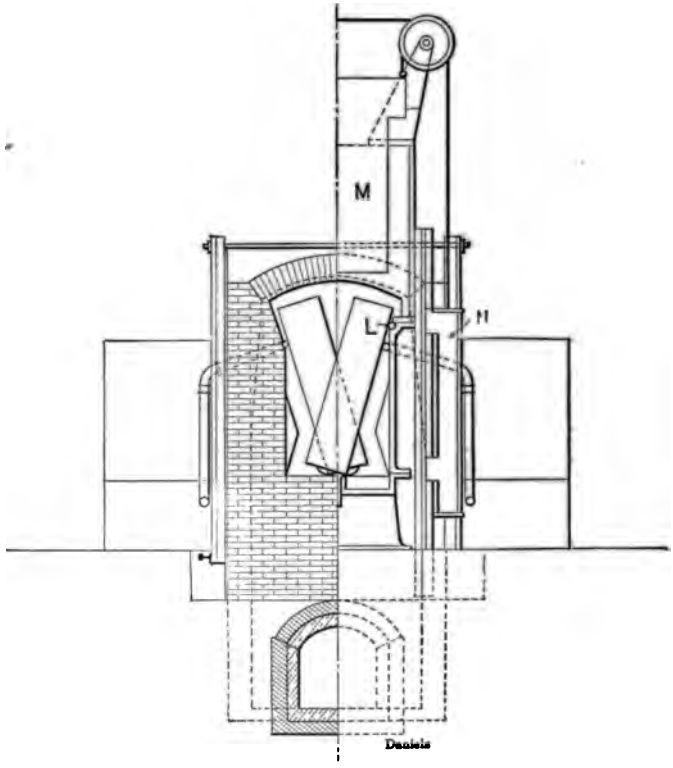


FIG. 249.

The pushers are also generally in exposed positions, and unless carefully protected, trouble is liable to be met with in cold weather. In brief, the hydraulic type of charger has been found inadequate to furnaces of this length owing to its inherent weaknesses, viz.: lack of speed and danger of breakage due to water hammer under high pressure.

13. To obviate these difficulties, an electrical pusher has been devised. This consists essentially of a long I-beam *O* running upon rollers, as shown, and provided with a cast-steel pushing head *P*.

On the lower portion of the I-beam is bolted, in sections, a cast-steel rack Q, the teeth of which engage with those of the pinion R, the latter being driven through a train of gears by the motor S. The latter is a series motor of the railway type, with rheostats and a controller. The speed of the pusher may consequently be varied over considerable limits, this feature being particularly desirable in rapidly withdrawing the ram from the furnace, which imposes only a light load on the motor, and consequently will be accomplished at a higher rate of speed. Considered from an economical point of view the electrically driven charger is preëminently adapted to the purpose, as the output of power necessary is in direct proportion to the effective work done. An auxiliary motor may be connected direct with the main driving gear, or independent on the pusher rack Q. In either case the two motors should be arranged for the ordinary system of series multiple control.

14. Briefly described, the operation of the furnace is as follows: The ingots one by one are placed by the charging crane so that they stand on the pipe B, the upper part resting against the rod L as shown in Fig. 242. They are alternately inclined to the right and left as indicated in the same figure. As fast as they are placed in position the door M is raised and the ingots are pushed into the furnace. As the heat increases gradually toward the firing end, they reach the proper temperature as they approach the latter place. When the ingot reaches the inclined part of pipe B it slides down and rests on the sand bottom C, the upper part leaning against pipe F, which locates the ingot in the correct position for withdrawing. The cover G is then opened and the ingot, which is now ready for the rolls, is extracted in the ordinary manner.

15. It will be noted that slag holes are provided on each side as shown at U and also at the end as shown at V, the floor of the furnace being graded accordingly.

This furnace, as equipped, possesses a number of commendable features.

First: Comparatively low first cost of installation.

Second: Considering the storage and heating capacity of this furnace, it occupies relatively a small floor place, besides being easily and quickly erected.

Third: Owing to the simplicity and accessibility of parts, the cost of repair and maintenance is reduced to a minimum.

Fourth: In the continuous furnace, especially the type which forms the subject of this paper, in which the ingots are alternately

inclined to the right and left, coupled with the continuous method of charging, a much better opportunity is given for an even heating on their sides, and in this respect the vertical furnace surpasses the horizontal and closely approaches the soaking pit; the even heating of ingots being one of the strongest arguments in favor of the latter.

Fifth: There is at all times a maximum amount of metal in the hottest region of the furnace, which is not true of any other type of ingot-heating furnace.

Sixth: If, as often happens, it becomes necessary to charge cold ingots, the superiority of the vertical continuous-heating furnace over all other forms is very marked, for its length is such that, after traversing say half the length of hearth, it is safe to say the temperature of the flame is about the same as when leaving the regenerative chambers of soaking pits. As a result, heat which escapes in the latter case is doing effective work in the continuous furnace preheating cold metal.

Seventh: As a consequence of the gradual decrease of temperature toward the charging door, cold ingots may be introduced into the furnace without danger of cracking, thus giving to this type of furnace a decided advantage over the soaking pit form in the treatment of high-carbon steels.

Eighth: The temperature of the burning gases decreases gradually from the firing toward the charging end, until, at the latter end, they are comparatively cool. Thus, the opening of the charging door does not result in great loss of available heat, as in the case of the soaking pit.

Ninth: On account of the high speed of the pusher, the door is kept open a comparatively short time, and the pusher itself is only briefly subjected to the intense heat.

Tenth: The ingot is handled in a vertical position from the time it leaves the steel mill until it is delivered to the mill tables. No high-pressure water is required in connection with this furnace, as air cylinders are found entirely satisfactory for operating the necessary doors and covers. Troubles incident to cold weather and the maintenance of such a system are thus avoided.

Eleventh: Owing to the method of applying the heat, it has been demonstrated in practice that the furnace waste and oxidation, or scale formation, is very much less in the vertical furnace than in the ordinary soaking pits.

Twelfth: Another advantage over the soaking pit practice is that segregation is greatly reduced because in charging hot ingots

the low temperature in the rear end of the furnace gives the inside core of the ingot a chance to solidify without losing the benefit of the initial heat in the ingot; and, furthermore, cold ingots that are already solidified can be charged in this furnace with greater economy, owing to the feature mentioned in feature sixth.

16. In conclusion, while this system of heating is advantageous in large plants, it seems to the writer to be especially adaptable to smaller plants producing from 100 to 200 tons of steel per day. In other words, for small-size plants it seems apparent that a soaking pit arrangement would be comparatively very expensive.

DISCUSSION.

Mr. S. T. Wellman.—I might mention a fact which Mr. Daniels does not state in this paper, that there is one of these furnaces in operation at the steel works at Worcester, and it is working very satisfactorily. This is almost the first effort to build and run a continuous furnace where the ingots are to be kept in their vertical position during all the time of heating. It may not be known to all the members, but it is a fact that almost all of the heating of small billets, say from two to four inches in section, in the United States, is now done in continuous furnaces. This is very satisfactory in many respects. One advantage of it is, that it is a cheaper furnace; for a furnace occupying a given space, it gets out a very much larger tonnage. But the principal advantage is that it is more economical in consumption of fuel than any other furnace. I think the average of fuel consumed in the continuous-heating furnace is not more than one-half the quantity which is consumed in the best regenerative furnaces which have been built. For rail steel a continuous furnace which heats a vertical ingot would be very desirable, because it is often the case that an ingot goes into the furnace while it is still liquid in the interior, and if that ingot is laid down on its side, the cavity due to the shrinkage of the steel in cooling might be in the middle of one side of the ingot, and might not appear until the rail had been rolled from the ingot and placed in service. The result of this has been disastrous on more than one occasion. That is the reason why ingots for the making of rail steel are almost universally heated in vertical

furnaces, in what are called the soaking-pit furnaces. As far as fuel is concerned, however, the vertical soaking-pit furnace is very uneconomical; because it is the most wasteful furnace in fuel of any which is used; especially is this the case when cold ingots have to be charged.

No. 897.*

BEVEL-GEAR CUTTING MACHINES AT PARIS.

BY FRED J. MILLER, NEW YORK CITY.
(Member of the Society.)

MOST of those who have visited the machinery building workshops of Europe must have noticed that the use of bevel-gear planing machines is more common there than here, and that the use of bevel gears with teeth cut by a formed rotary cutter is correspondingly less common there than in our own machine construction. They seem to have more generally recognized the fact that, in order to get a properly shaped tooth in a bevel gear it must, generally speaking, be planed, and that where the teeth are of any considerable length, the errors of form resulting from the use of formed cutters are very considerable, and inadmissible for what may properly be regarded as the best work.

A machinery exhibition held in Europe might therefore be expected to afford many examples of machines for planing the teeth of bevel gears, and in the Paris Exposition of last year six such machines were shown, all of them noteworthy, and, in one way or another, interesting; most of them differing one from the others as much as it would seem to be possible for them to differ, in view of the fact that all were for the same purpose. Of these six machines five were of foreign design and origin—one English, two French, two Swiss, and one American. Another American machine exhibited, and which is described in this paper, does not plane the teeth, but mills them, though it does not use a formed cutter, but copies a generated tooth curve by a cutter having a plane cutting surface. Only two of the gear planing machines generate the tooth; all the others copy a tooth template or pattern.

At Fig. 250 is an interesting bevel-gear planer of French design. In its general design this machine is very similar to

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

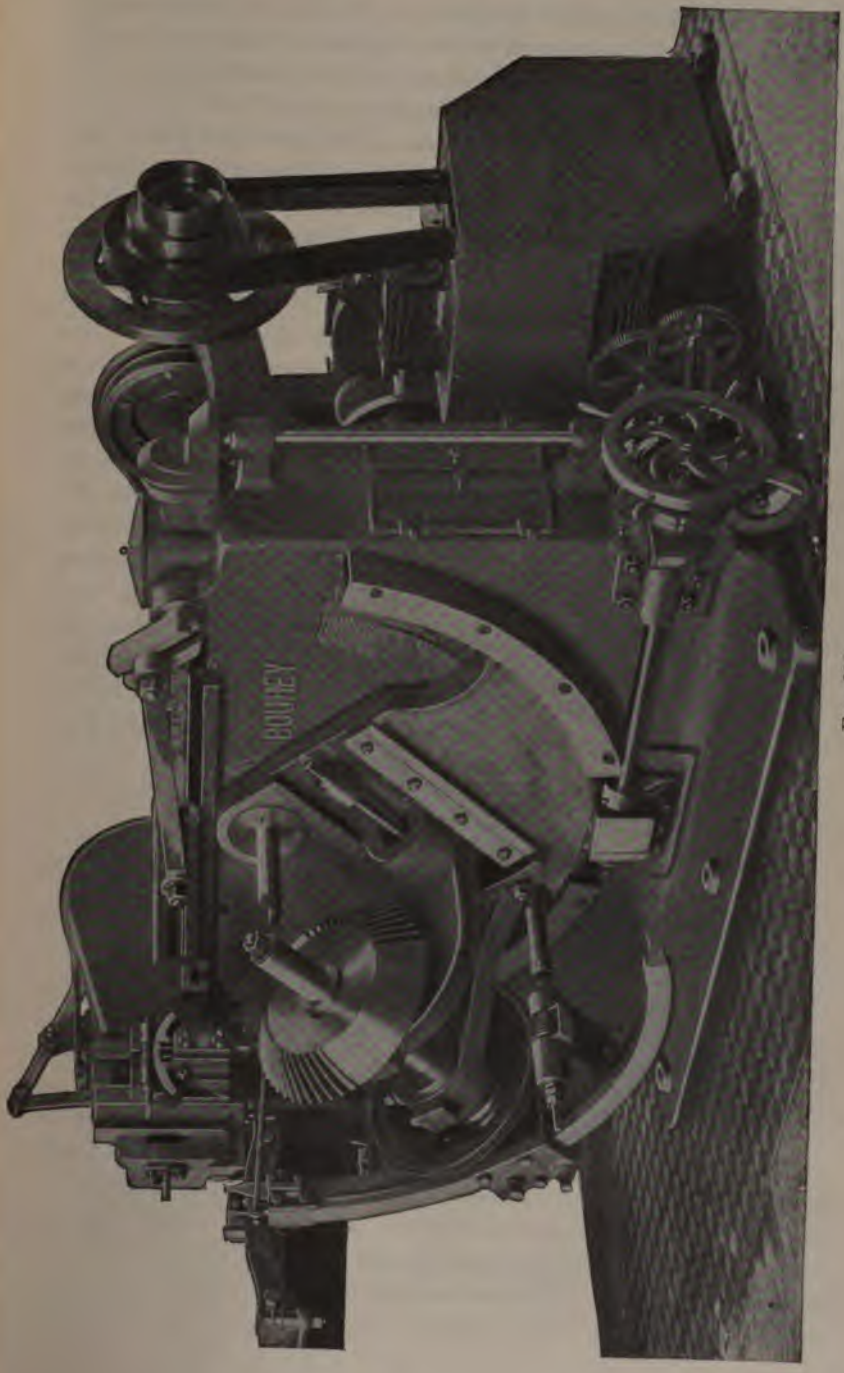


FIG. 250.

many others that are to be seen in British and Continental workshops, but it has what I believe is a new feature in its provision for cutting helical instead of straight teeth, where the former are desired, as they seem to be so often by French and other Continental machine builders. This machine forms the tooth by copying an enlarged template. It is built by Usines Bouhey, an incorporated company having workshops in Paris at 43 Avenue Daumesnil. The bevel-gear planer resembles somewhat the Richards side planer—*i. e.*, it has on its bed a saddle which is fitted to suitable guiding surfaces, and reciprocated by the slotted crank and connecting rod seen at the right of the machine. This saddle has a projecting arm, on which is a smaller saddle resembling those used on planers, and carrying the tool in much the same manner. The blank to be planed with teeth is mounted upon an arbor *J*, Fig. 251, which can be placed at the proper angle by adjusting a sector plate *Y*, which is fitted to the front side of the base of the machine and is pivoted near the top, where a spindle is seen projecting from this pivot, and is terminated by a cone which has been flattened on the upper side to facilitate setting the blank, so that the apex of the pitch cone will coincide with this centre. This is done by adjusting the projecting arm which is fitted to the face of the sector plate, and which, by means of the screw *K*, Fig.

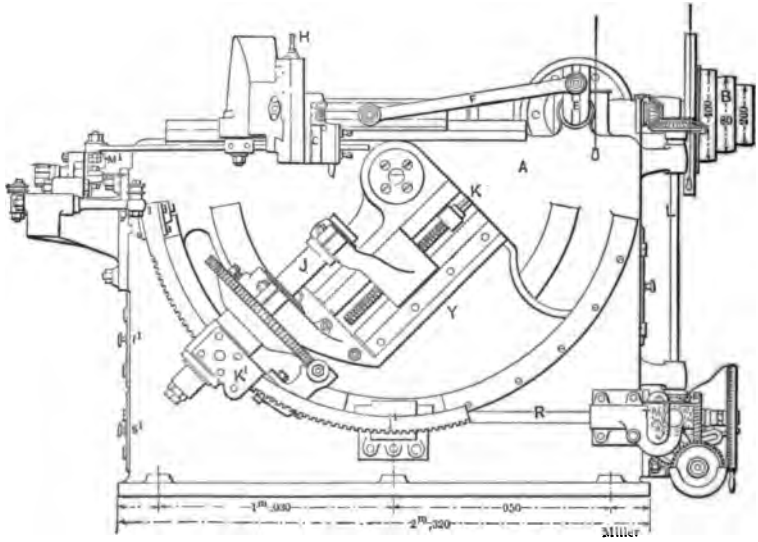


FIG. 251.

251, can be moved in a line parallel with the work arbor until the blank is at the right height. The feed takes place by the rotation of the sector plate (clockwise), worm-teeth being cut in its periphery for that purpose, which are engaged by a worm on the shaft at the right, near the bottom of the machine. The indexing is by means of the worm and wheel below the blank, and the template is seen attached to the upper end of the curved bar J^1, which passes through a bearing at the lower extremity of the work-holding arbor. This bar is rotated in a vertical

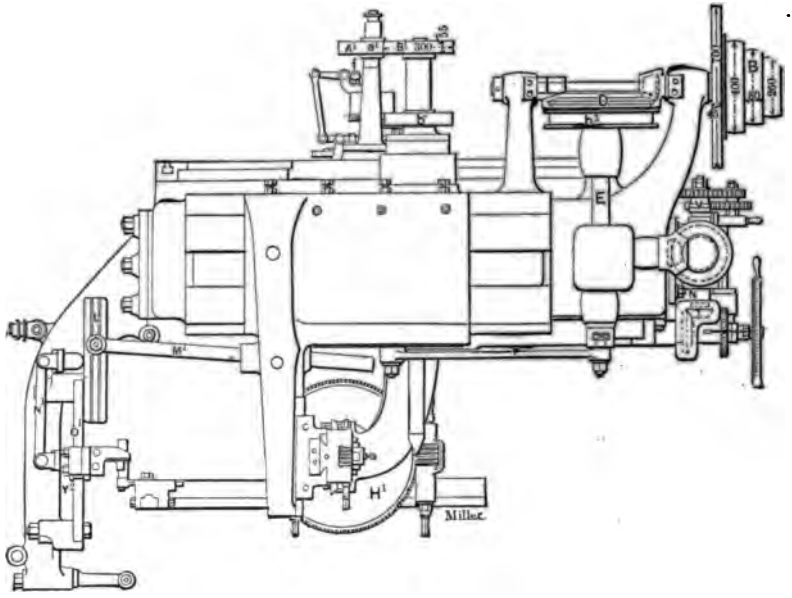


FIG. 252.

plane with the sector plate by the feed motion, and as its upper extremity rises it carries the template with it, and the template resting against a knife-edge, and being held against it by a weight, causes the blank to be rotated as the feed takes place, so as to reproduce the form of the template in the tooth being cut.

So far as described the machine would produce only straight teeth of the ordinary kind, but by additional mechanism, which is not clearly shown in the photograph, but can be seen in Figs. 251 to 254, it will cut helical teeth like those seen on the blank that is in the machine, and which has been partially cut.

To produce this effect it is of course clear that the blank, the curved bar J^1, the template, the point against which the template rests, and all their belongings, must be given an independent rotary motion as the tool passes along the side of a tooth, and, during the back stroke of the tool, must be returned to be again rotated the same amount during the succeeding cutting stroke. This motion is secured by attaching to the projecting arm the connection M^1, Fig. 252, which engages with the vibrating, slotted arm L^1 at any required distance from the

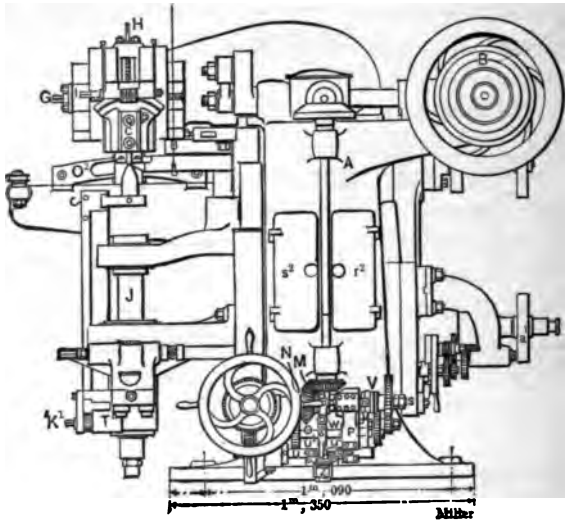


Fig. 253.

centre, and the arm L^1 thus gets a vibrating motion from the movement of the tool-carrying saddle; the ratio of this movement to that of the cutting tool depending upon the distance from its centre at which the connection M^1 is attached to the bar. From this point motion is transmitted by the connection N^1 to a sliding block which is fitted to the bar O^1. This sliding block carries the knife-edge, against which the tooth template is held by a weight and cord passing over suitable guide pulleys. This sliding block can be held in a fixed position by a pin, and when so held the machine cuts straight teeth; but when this block carrying the knife-edge is given the reciprocating motion derived in the manner described, the tooth is approximately a helix.

It is evident that when the curved bar J^1 is rotated upon the axis which coincides with the axis of the gear being cut, any given point in the template will move in an arc of a circle. It moves in such an arc when its motion is controlled by the template itself, and, of course, must do so when moved by its connection to the sliding block, which is in turn moved upon the bar O^1 by its connection to the tool saddle. But if this sliding block which carries the guiding point for the template moved in a straight line, its position on the template would be altered during the cutting stroke, because the template moves in an arc of a circle. For this

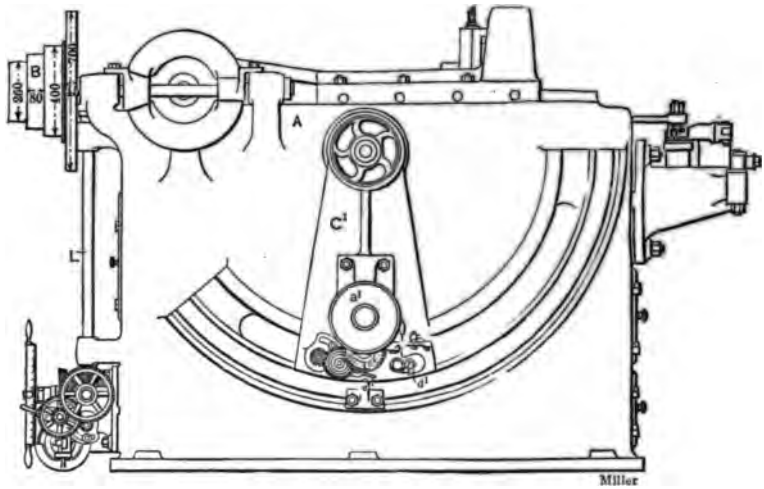


FIG. 254.

reason the bar is curved, as shown at Fig. 253. In fact it corresponds to the geometrical pitch circle, *ab*, of the bevel-gear drawing, Fig. 255, although, of course, its radius is enlarged in proportion to its distance from the apex of the pitch cone and for the same reason that the template is also larger than the teeth to be planed.

It has been shown by American practice that if you have practically perfect bevel gears which are set to engage precisely as they should and can be kept in such engagement, the result is all that anyone could possibly ask. But these conditions are not always secured here, and probably are not more nearly secured anywhere else; and if small errors of form and of position are bound to be present, then perhaps it is better to

have helical instead of straight teeth, and, if so, then this machine seems to afford a very good means of getting them.

The feed and quick return motions are given by the mechanism shown at the right of the machine in Figs. 251 and 252 and near the floor line in Fig. 253, while the indexing mechanism is best shown in the rear view of the machine, Fig. 254. It is attached to the plate C^1, which in turn is connected to and rotates with the sector F on the front of the machine.

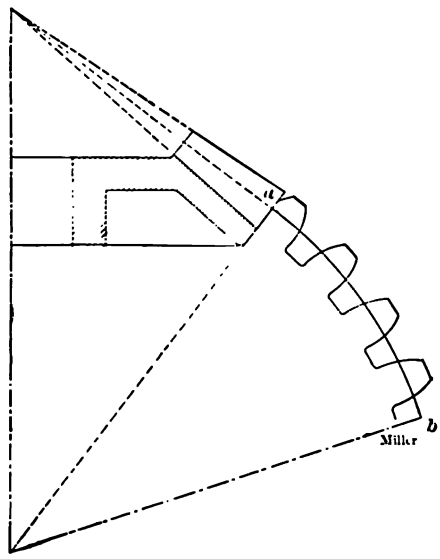


FIG. 255.

Bevel-gear Planers by the Maschinenfabrik Oerlikon, of Oerlikon, Switzerland.

Two machines which are not automatic, except as to their feed motions, were exhibited by the Maschinenfabrik Oerlikon, of Oerlikon (near Zurich), Switzerland, which, while they are not startlingly new in principle, are yet very interesting for the ingenious and creditable manner in which their design has been worked out. The smallest of these machines, which is designed for wheels up to 200m/m (7⅞ inches) diameter, with teeth 50m/m (2 inches) long, and for pairs of gears having a ratio of 1 to 6, is shown in Figs. 256, 257, and 258. The only automatic functions it

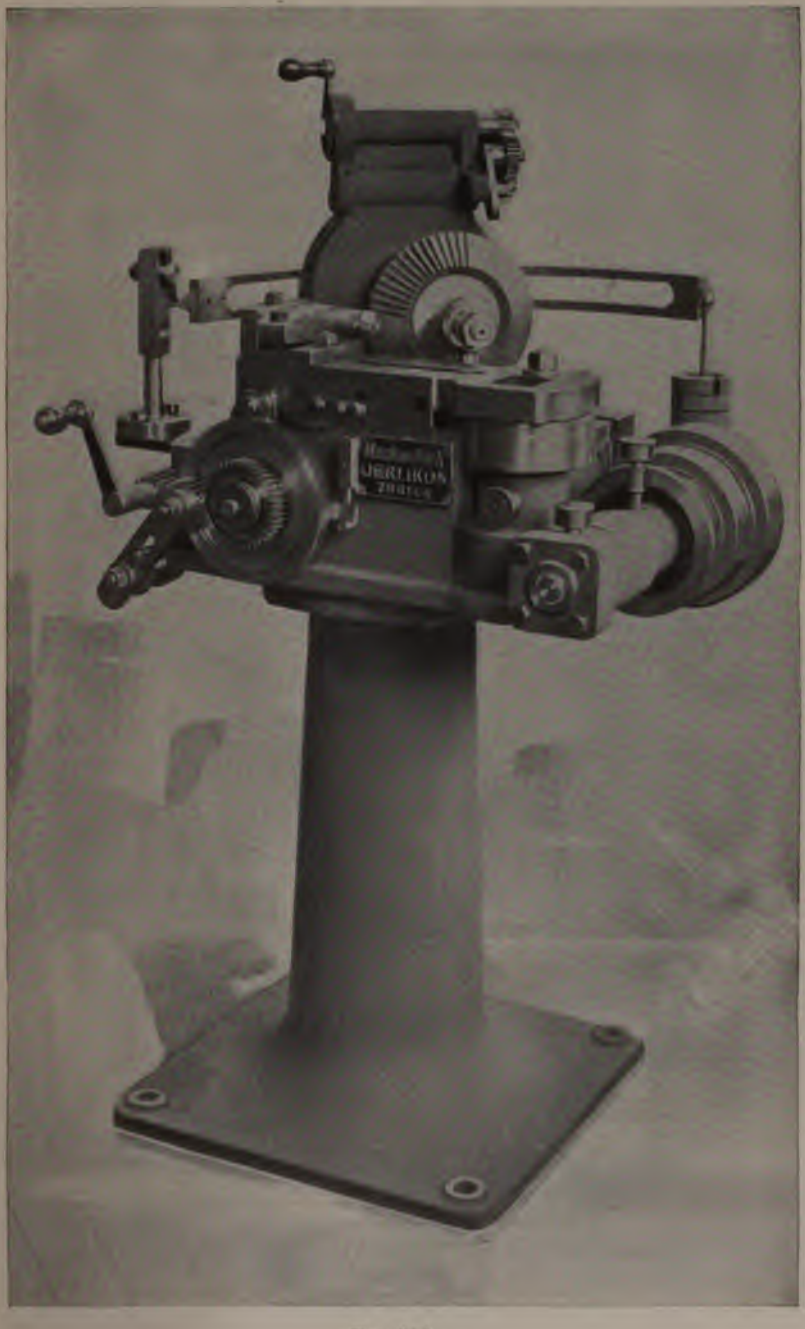


FIG. 256.

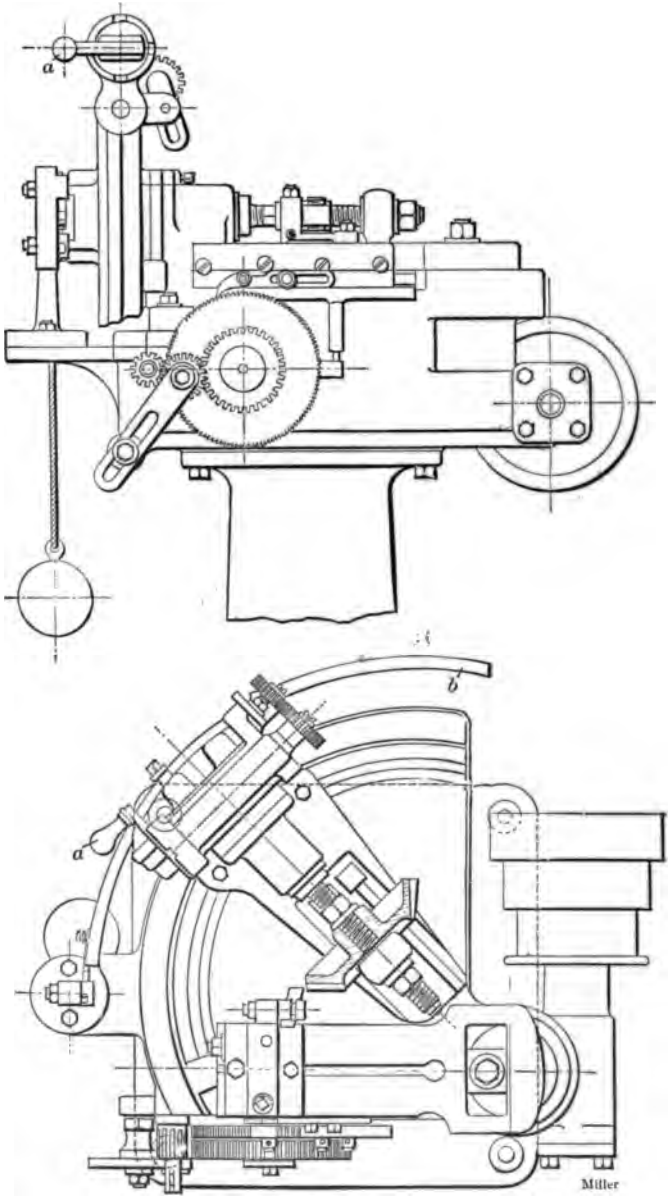


FIG. 257.

possesses are the feed and the release of the same, it being necessary to run the tool back, index the blank, and set a new cut each time by hand. The photograph gives a good idea of the general appearance of the machine, and by reference to the drawings it will be seen that the blank to be cut is held upon an arbor supported in a head which can be set at any required angle upon a large plate, which is given the slight circular motion required for the feed by means of a worm. The indexing

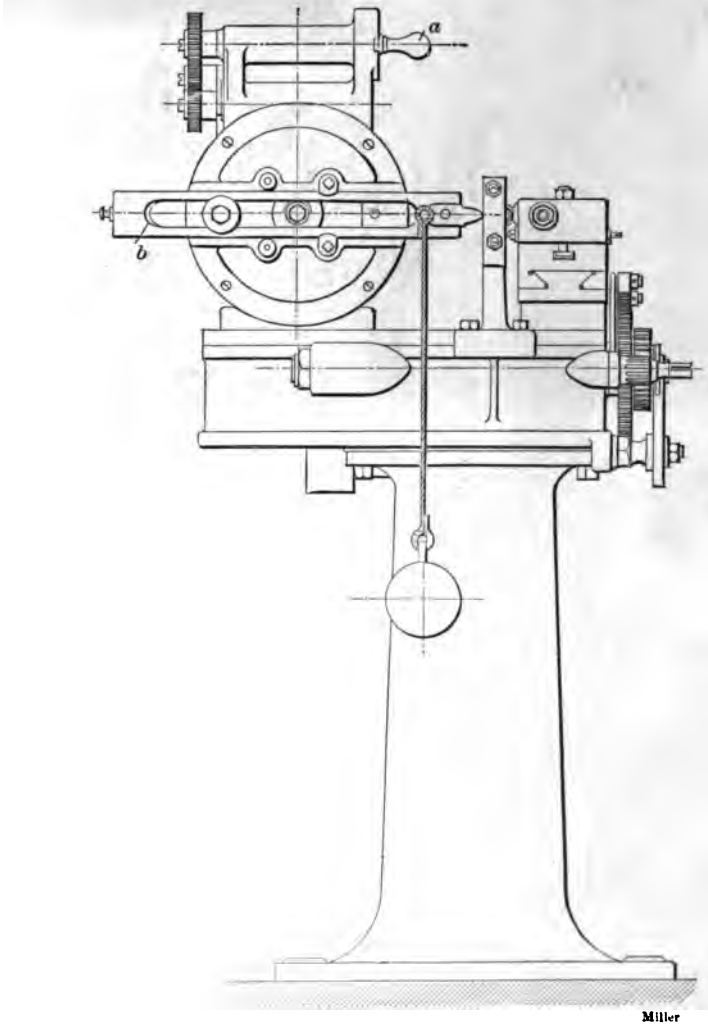


FIG. 258.

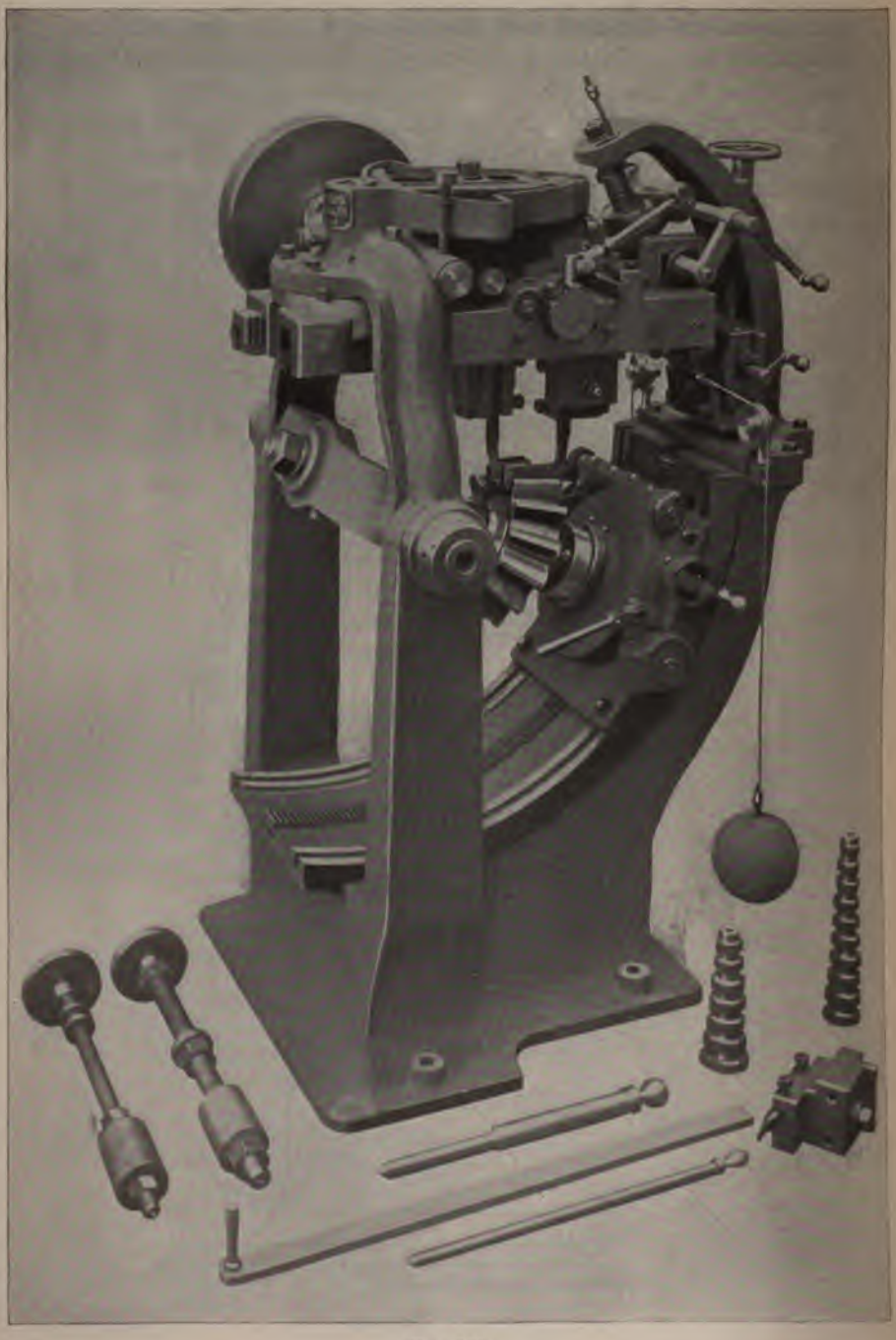


FIG. 259.

for the teeth of the blank is done by integral movements of a crank handle, *a*, change gears being supplied to give the correct indexing. The work arbor passes through a sleeve, which also is adapted to rotate within the head, and is made to do so as the planing of the side of a tooth proceeds by means of the tooth template seen attached to the end of the slotted arc *b*, this arc being attached to the sleeve and counterweighted so as to keep the template at all times in contact with the guide point. The template is, of course, so located that it is the same as though it were a section of the tooth being planed, but carried out to a larger diameter of the wheel.

The cutting tool is given its reciprocating motion by means of the Scotch yoke seen in the plan view, Fig. 257, the crank pin being upon a disk which is driven from the cone pulley by means of worm gearing. The block which holds the tool is adjustable radially upon the slide to suit the size of wheel being cut, and there is also a slight movement at right angles to this for adjusting the tool to its proper position. The feed motion is taken from the tool slide, and the automatic release of the feed is provided for by omitting some of the teeth in the ratchet wheel, so that when this part of the wheel reaches the pawl there can be no further feeding.

The second machine, which is designed for wheels up to 500m/m (19¾ inches) diamater, with teeth 200m/m (7⅞ inches) long, and for pairs of gears having a ratio of 1 to 6, employs the same principle as the smaller machine—*i. e.*, it uses a template from which the tooth shape is copied—but this machine uses two tools, which cut simultaneously on opposite sides of the same tooth, the tools always moving in opposite directions; that is to say, when one tool is beginning its cut at the inner end of a tooth, the other tool is beginning its cut at the outer end of the same tooth, but on the opposite side of it. The indexing and the setting for each new cut are performed by hand, the same as in the case of the other machine. There is a base *A*, Figs. 260 and 261, having a curved seat for a saddle, that carries the threaded work arbor, this curved seat being an arc of a circle having its centre at *B*. The blank is adjusted on the arbor and the saddle is adjusted upon the curved seat of the frame of the machine, so that the apex of the pitch cone of the wheel to be cut is at *B*, a straight-edge or gauge being applied to a groove provided for that purpose in the surface *a* of the

machine and to the upper surface of the blank. The outer end of the arbor is supported by the yoke, which has trunnions supported at the point *B*, and about this same central point *B* turns the upper portion of the mechanism which supports the tool slides and other parts which transmit motion to them. The

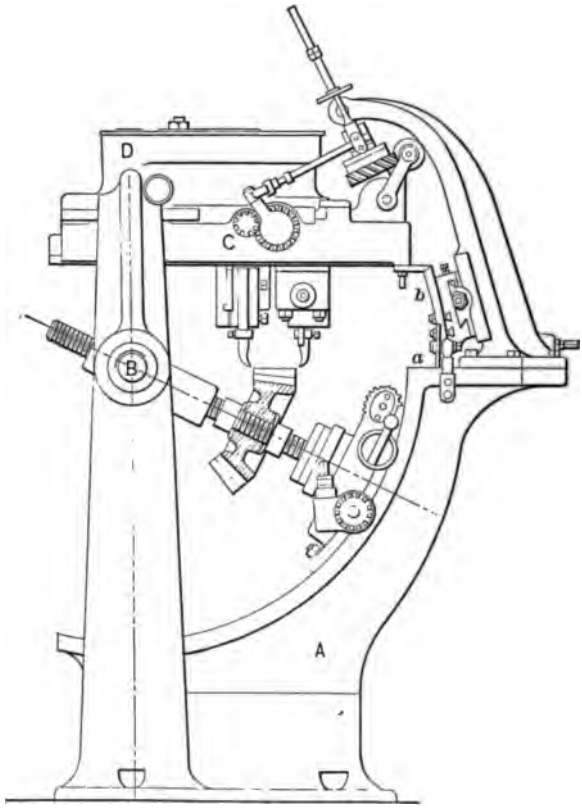


Fig. 260.

piece *C* in the side view of the machine, Fig. 260, is one tool slide, and behind it is a similar one, as shown in the end view, Fig. 261, and also in the photograph. These two slides are each pivoted so that they may swing about a centre common to both and vertically over the centre *B*. They are free to turn about this centre, and their inner ends have counterweights attached to them in such a manner that the two slides always tend to approach each other; but they are allowed to do this only as deter-

mined by the form of the template, which is placed at the point *b*.

Within the two tool slides mentioned there are rams which have attached racks, and both these racks are engaged on opposite sides of and by the same pinion, which latter is on a vertical

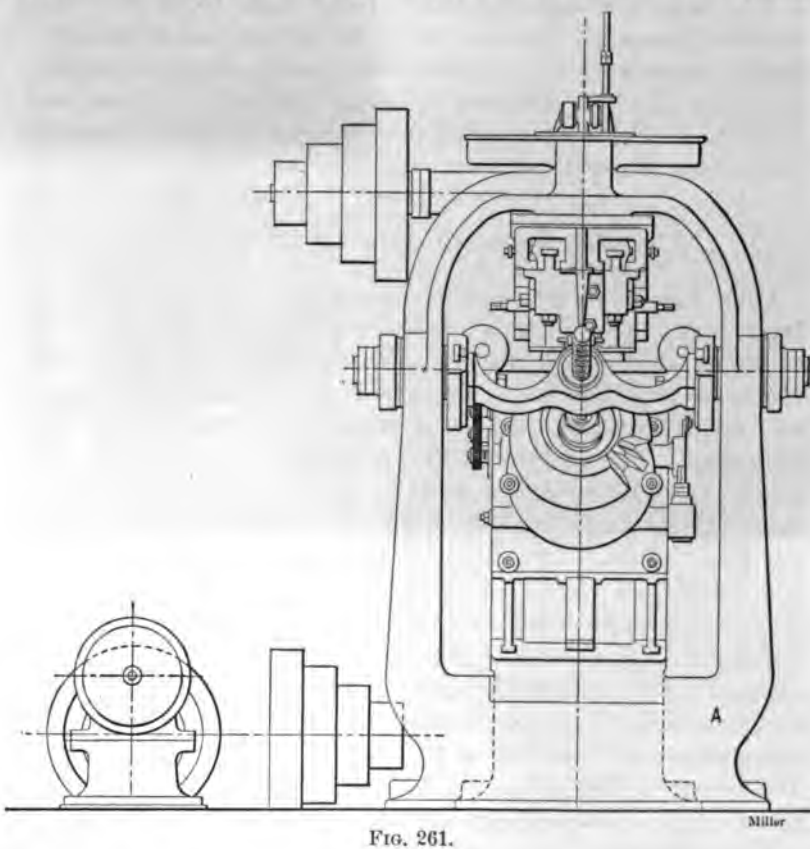


FIG. 261.

shaft passing downward and concentric with the vertical centre line *D*, this shaft having at its upper extremity another pinion, by which it is driven by the teeth of a sector, which sector is oscillated by a crank on the face of a worm gear, which crank works in a slot formed in the sector and thus gives a quick-return motion to the tools. From one of the rams the feed motion is derived in the manner clearly indicated by the photograph, and there is an automatic release for this which operates to prevent the pawl from engaging when the cut has gone to the

desired depth. Where teeth are to be planed from the solid, a tool holder is provided for one of the rams, which brings the tool over the centre of the blank, this being, I believe, shown lying on the floor, together with the other appurtenances required for operating the machine.

The fact that opposite sides of the same tooth are being operated upon at the same time is obviously an advantage in that it imposes upon the blank-holding mechanism less disturbing force likely to produce errors of spacing or of form, aside from the fact that it considerably reduces the time necessary for planing a wheel.

The Monneret Generating Machine.

Only two machines were shown at Paris that generate the tooth form. One of these makes a tooth of the involute form, or, to be more exact, the octoid tooth, making use of precisely the same principle as is employed in the machine invented, and for many years used, by a member of this Society, Hugo Bilgram, of Philadelphia. The mechanism of the machine is, however, entirely different, and its action is also different in so far as it necessarily produces a helical tooth instead of a straight one; and, during the cutting of the teeth a cut is made along the side of all the teeth in the blank before the tool is fed deeper into the blank, so that instead of one tooth space being finished before the next space is begun, all the teeth are at any given time practically equally near completion. The machine is quite a recent invention, the first one constructed being shown at Paris and by the engravings herewith presented. Its inventor is Mr. L. Monneret, who is the directing engineer of the machine-tool-building establishment of H. Ernault, of Paris.

The cutting tool represents a tooth upon a crown gear; it reciprocates for its cutting action, while at the same time it is rotated in the arc of a circle representing the crown gear. The blank being cut is at the same time rotated at its proper relative rate, the same as though both the crown gear and the gear being cut were complete and were in engagement with each other. The principle is illustrated by Fig. 263, in which *A* may represent the pinion being cut, and *B* the crown gear, all the teeth of which are, in the machine, removed, except one, which, representing a section of a tooth of the crown gear, is made of steel,

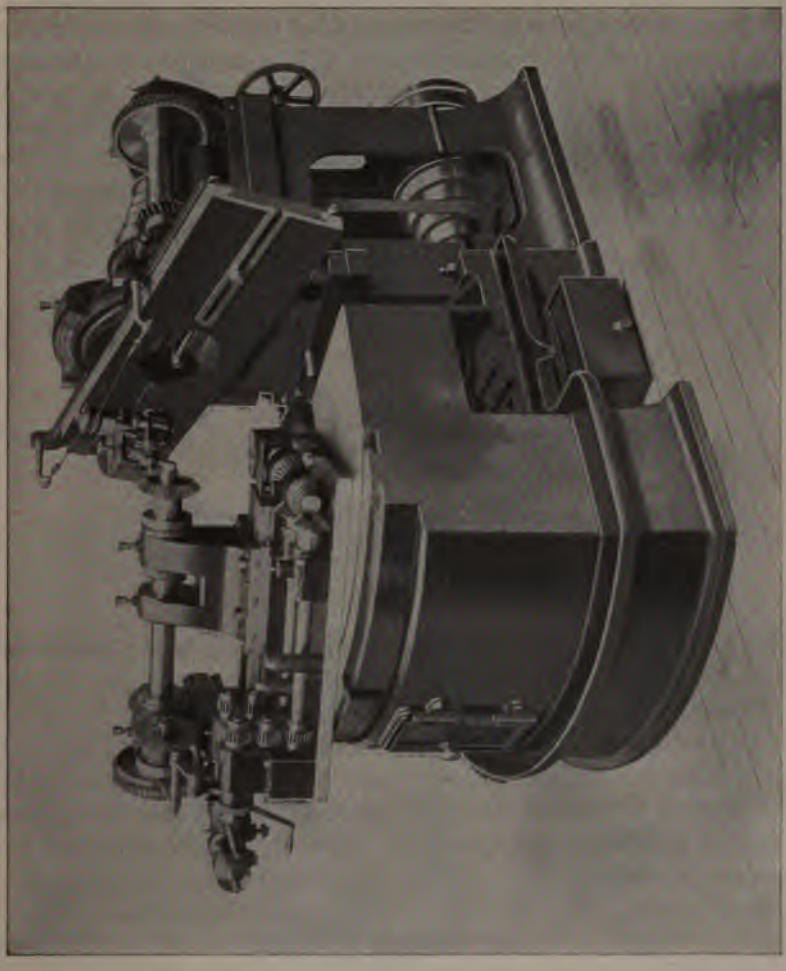


FIG. 262.

receives a reciprocating motion, and is otherwise adapted for cutting the teeth of its mating wheel as they both rotate. Fig. 264 gives a plan view, and elevations from three different viewpoints are given by Figs. 265, 266, and 267, in which *A*, Fig. 264, is the cutting tool, not however shown as it is actually made, for it is really a turned tool made in the lathe, as shown in the photograph. *B* is the work arbor, which is mounted in a saddle that rests upon the base of the machine, is pivoted at *C*, and can be set at any angle, to suit the gear to be cut. The cone pulley and back gears shown do not give a rotary motion to the main spindle and the tool slide, but serve only to impart the required reciprocating motion to the tool by means of a crank

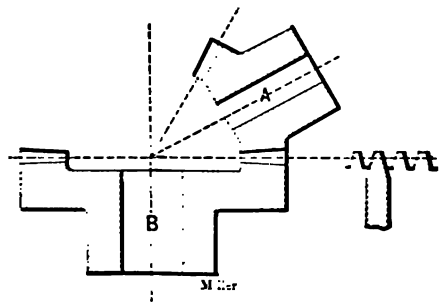


FIG. 263.

disk and connecting rod, a portion of said rod being visible in the photograph, Fig. 262.

When the machine is in action, the blank being cut continuously rotates at such a speed relative to the motion of the tool slide that the latter makes as many cutting strokes during one rotation of the blank as there are teeth to be cut in it, this ratio of rotative to reciprocative movement being obtained by simply putting on (by a table) the proper change gears at the end of the machine, the same as in gearing up a lathe. Thus, the tool makes a cut along one side of a given tooth, is lifted out of its path for the return stroke by the friction device worked by the cord seen in Fig. 262, and, when it makes its next forward stroke, takes a cut along the corresponding side of the next tooth, the rotation of the blank meantime having been just right for the proper indexing.

Since the rotative movement of the blank is continuous and takes place while the tool is moving in a straight, radial line,

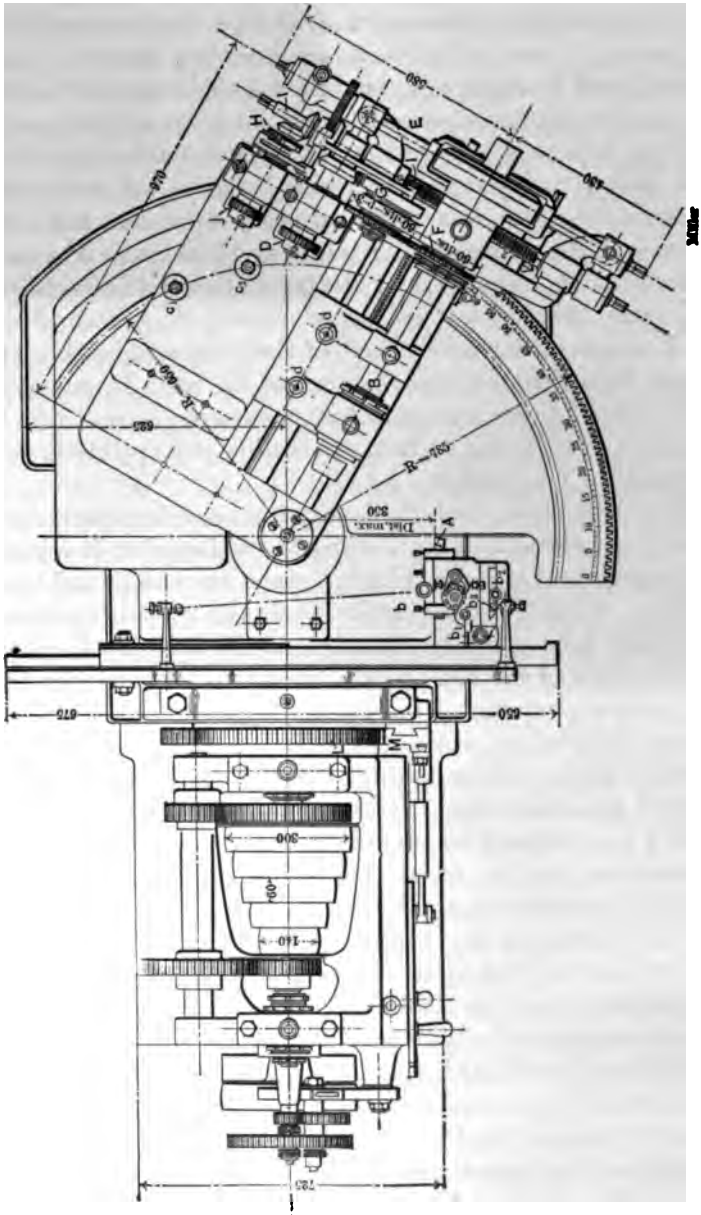

Miller
680
480
480
H
E
F
D
C
d
B
R 765
R 600
620
320
Dist. max.
A
b
b1
675
250
M
300
140
125

FIG. 264.

the tooth produced is, of course, helical, or what would commonly be called spiral, instead of straight, as we are accustomed to cut them. These helical teeth are, however, claimed to be an advantage and to conduce to smooth running; while it is to be noted that the machine automatically takes care of the point of having the helices of two mating gears match each other, for the simple reason that the mating gears, being of the same pitch, must have the same rotative speed at the pitch line relative to the motion of the cutting tool, regardless of their size or number of teeth, in order to make the indexing right; and if they rotate at the same lineal, pitch-line speed during the cutting stroke, then, of course, the pitch or lead of the helix will be the same. It follows from this, too, that the pitch of the helix is not subject to the choice of the operator, but necessarily varies with the pitch of the gear, being, in fact, not readily perceptible in gears of moderate or fine pitches.

It should be noted that the teeth produced by this machine are not true helices, but that, owing to the fact that the motion of the cutting tool is derived from a crank movement and therefore varies during a cutting stroke, while the rotative movement of the blank does not vary, the angle of the helices will vary at different points of the same tooth. I suppose it is important to have the same over-run of the tool at each end of the teeth in all gears intended to work together; because, for the reason mentioned above, unless the cut takes place during the same portion of the total cutting stroke of the tool the angles of the teeth of a pair will not match at all points.

It must be kept in mind that the cutting tool is set, or rather that the blank is set in relation to it, at the full depth of the tooth before cutting begins; that the plate which carries the reciprocating tool slide is rotated one way or the other about its centre until the tool or, in other words, the single tooth of the crown gear is brought into contact, and again out of contact with the blank; and the feed motion consists of simply rotating the face gear (or the tool-slide carrying plate), to carry the cutter through what would be the arc of action, or of engagement of the crown gear and its pinion. This is simple enough so far as the tool slide is concerned, because the plate upon which it slides has no other motion, and needs only to be rotated slightly at the end of each complete rotation of the blank to give the tool a new cut, but at the same time the wheel being

cut must be given a corresponding rotative motion in order to generate the tooth curve; and since this blank already has a continuous (and relatively rapid) rotative movement—equal to one tooth for each cutting stroke—the rotative movement necessary for the generation of the tooth curve must be simply a modification of the rotative movement already taking place. It is this which makes the machine rather complicated, but the means by which it is accomplished are exceedingly interesting, and are of such a nature as to make the setting up for any given job of gear cutting exceedingly simple and easily performed, the machine itself taking care of its most intricate functions automatically.

The change gears give motion to a shaft which passes through under the cone pulley shaft to a point near the central pivot *C*, where it drives a bevel gear having a vertical axis concentric with said pivot. Part of this shaft is seen in the photograph, Fig. 262.

From this bevel gear is driven the short radial horizontal shaft also seen in the photograph, which shaft *seems* to have upon it three mitre gears; it is really a sleeve and shaft, each with independent rotative motions, as will be explained further on. The continuous rotative movement for the blank is thus carried from the change gears, through the vertical pivot *C*, and the inner one of the two horizontal parallel shafts seen in Fig. 262, to the inner one of the two similar spur-gear trains disposed vertically and seen at the left of Fig. 262; the uppermost one of these being seen in the plan, Fig. 264, and there designated *D*. From here this motion is carried, by means not necessary to trace out in detail, to the worm shaft *E*, which rotates the work spindle and blank.

The feed motion takes place intermittently at each complete rotation of the blank, and it now remains to trace it out. On the work spindle is a spur gear, seen plainly in Fig. 262, and designated *F* in the drawing, Fig. 264. It drives an equal spur gear that gives motion to a slotted crank disk, and from this disk the feed ratchet wheel *H* is driven by a reversible pawl. This ratchet wheel is thus given a movement at each rotation of the blank, which intermittent rotation is carried through the mitre gears seen at the right of it in the plan view, to the screw *I*, which is parallel to the worm shaft *E*, and the worm is splined on *E*, so that it can slide upon it; being held in a sort of cradle or box, which extends over the screw *I* and is fitted to the latter, so that, when the screw *I* is rotated, it moves the worm longitudinally upon

the splined worm shaft *E*, and the worm thus acts as a moving rack to rotate the worm wheel and work spindle independently of the motion imparted to the same worm wheel by the same worm, by virtue of its rotative movement. It is this longitudinal movement of the worm, acting as a rack, that modifies the rotative movement of the blank to agree with the rotative

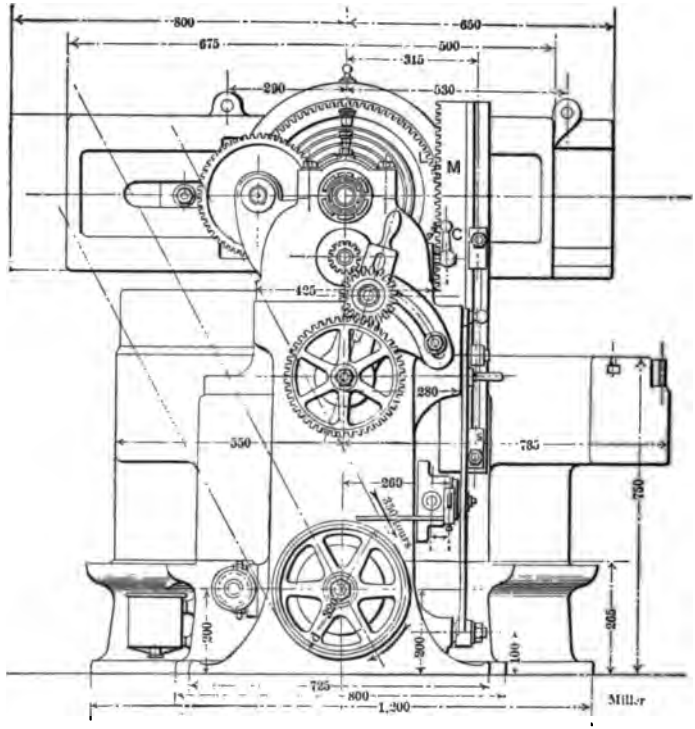


Fig. 265.

movement of the tool-slide plate (or crown gear) for the feed, as previously mentioned.

Since the blank and the tool-slide plate must rotate together for the feed at the proper ratio, further mechanism of an interesting character is provided for accomplishing this. At the other end of the shaft on which the ratchet wheel is placed is a spur gear (marked *J* on the plan, Fig. 264), and this gear is the driver of the outer one of the two similar trains of gears seen side by side near the left of Fig. 262. Thus motion is given to the outer one of the two parallel horizontal shafts and to the outer gears

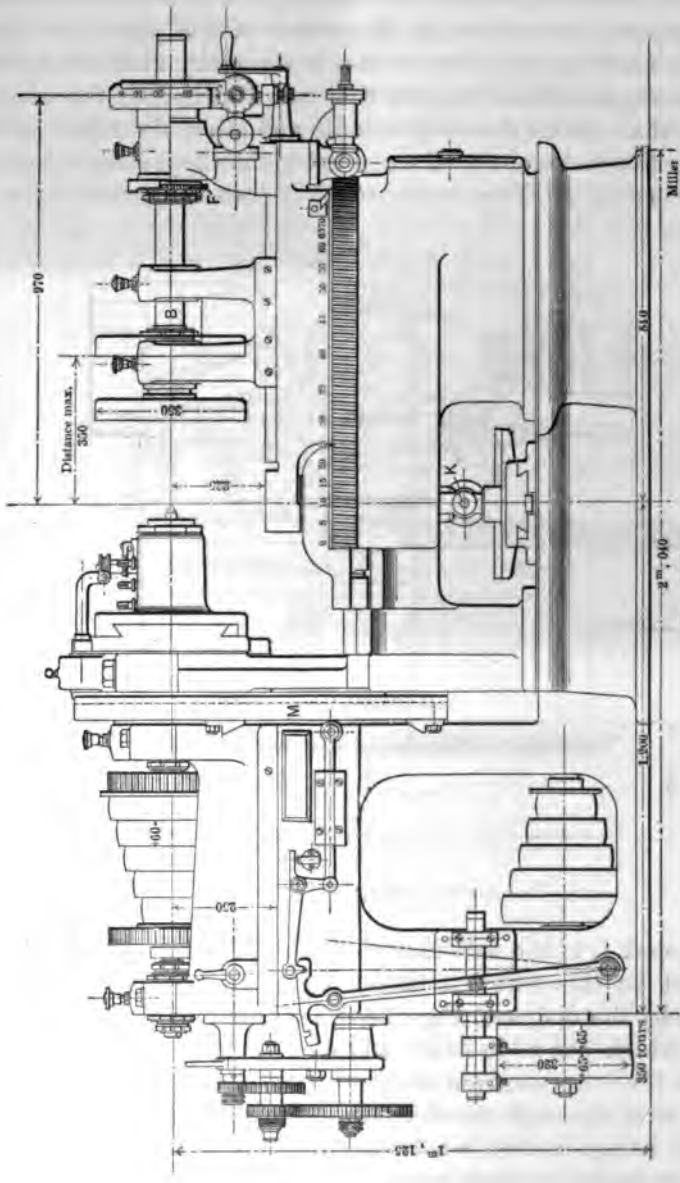

970
Distance max.
350
330
B
K
M
Miller
810
2m.040
1m.800
60
230
320
1m.125

FIG. 266.

seen, which move a shaft passing through the before-mentioned horizontal radial sleeve to the central pivot *C*, where it moves a shaft passing down through the centre of this pivot, and gives motion below to a screw which lies horizontally under this pivot, and is supported in brackets that are attached to the pivoted saddle that carries the work spindle and other described mechanism; this last-mentioned screw being thus kept always parallel to the screw *I*. The centre of this last-mentioned screw is

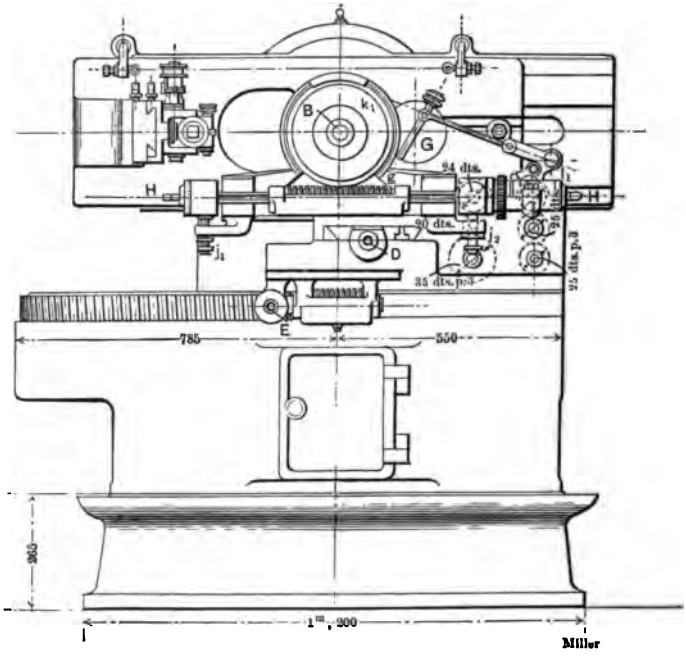


Fig. 267.

designated *K* in the side elevation of the machine, Fig. 266, and the nut on this screw is also a slide; the arrangement being shown by the diagram, Fig. 268, where the nut is pivoted to a block which can slide in *a*; and as *a* is rigidly attached to the slide *b*, the latter is given motion by the screw, the rate of which varies with the angle to which the screw is set; the motion of the nut being, in fact, resolved into two components, which are at right angles to each other. This lower slide *b* has a rack attached to its under surface, and this rack, by rotating a shaft with a pinion, gives motion, through a train of spur gears, to the plate which carries the tool slide, and the rate of this motion of

course depends upon the angle of the screw, which again is always parallel to the screw *I*, the position of which is determined by the angle of the pitch cone of the gear to be produced; so that this proper relative motion of the blank and of the plate or slide representing the crown gear is always automatically secured in setting the saddle to the proper angle, and needs no attention from the operator. The final gear of the last-mentioned train *L*, Fig. 265, has a vertical rack, *M*, engaging with it, which rack, by means of movable tappets, seen in Fig. 265, releases the belt shipper and allows the machine to stop.

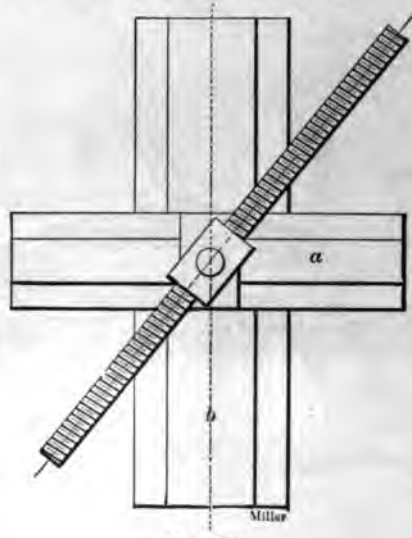


FIG. 268.

The Smith & Coventry Generating Machine.

The other generating machine exhibited at Paris is shown at Fig. 269. It was shown by Smith & Coventry, of Manchester. Like the machine last described, the blank is rotated a tooth space for each cutting stroke, but, unlike the French machine, the blank does not rotate during the cutting stroke, and the tooth is straight instead of helical. Both sides of a given tooth are operated upon at the same time—there being two cutting tools instead of only one, and the tooth curve, instead of being involute, is an arc of a circle, which is generated upon the principle of the odontograph. In other words, the tooth form is a circular approximation to the involute.

In this machine the blank to be cut is placed upon an arbor or spindle, which also carries the index plate, and which in turn is mounted on a saddle or head that is pivoted at a point on a line passing through the apex of the pitch cone, and the feed takes place by swinging this head upon the aforesaid pivot; this feature being the same as is found upon several other bevel-gear cutters. From this point, however, it is quite a radical departure, and the method of its operation will be best understood from the drawings, Figs. 270, 271, and 272. There are not only two cutting tools, but also two tool rests and two tool slides as well.

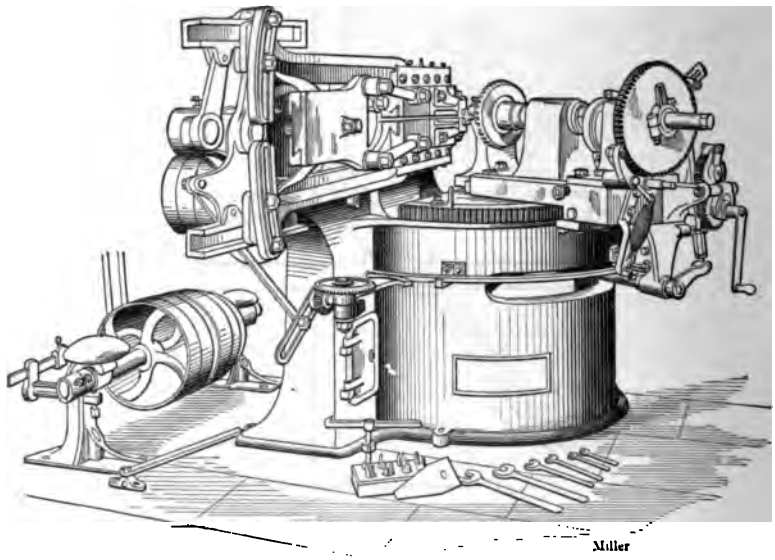


FIG. 269.

At Figs. 270 and 271 the tools are designated by the letters AA', and the tool rests are moved upon the slides BB' by means of the connecting rods CC', which are both attached to the cross-head D, that in turn is moved by the rod E from the crank plate F, which carries an adjustable crank pin.

The two tool slides are not fixed in position, but both are pivoted at the same point (G), and the cutting edges of the tools are so placed as to move in lines that converge at this point, which is in a line intersecting the vertical line on which the blank-carrying and indexing spindle also pivots, as previously

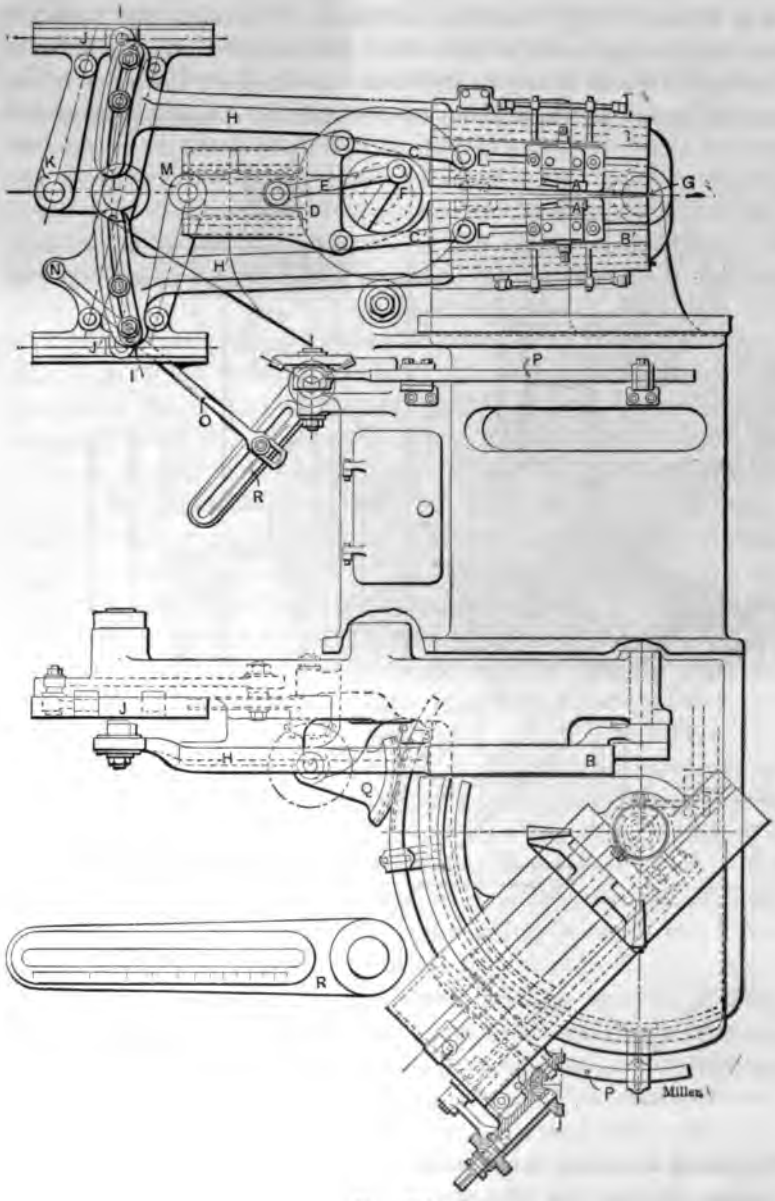


FIG. 270.

explained and as shown in the plan views, Figs. 270 and 271. At each stroke of the machine the blank is rotated one tooth, so that, supposing a cut to have been just taken along the sides of one tooth, the next stroke will make a cut along the sides of the next adjacent tooth, and so on around the blank; after which

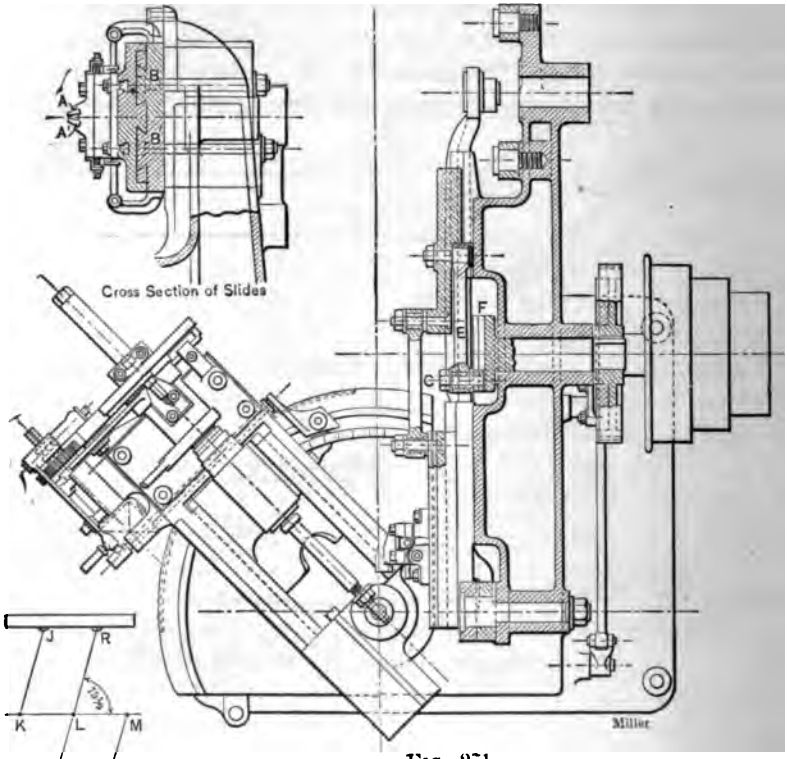


FIG. 271.

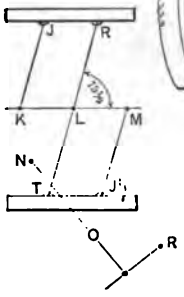


FIG. 272.

the blank-carrying arbor is swung in by the feed mechanism, the proper amount for the next cut around the blank; this feed motion being accomplished by means of an eccentric placed upon the blank-carrying spindle, which eccentric, by suitable mechanism, rotates a worm that engages with the teeth cut in

the edge of the bed of the machine. With the mechanism thus far described, it will be plain that if the machine were set at work it would plane teeth in the blank that would be rectangular in cross-section, but tapering lengthwise in both width and depth; tending, in fact, to a point at the apex of the cone, on the line passing through the centres of the pivots previously referred to. But the cross-section of the tooth to be produced is required to be defined by arcs of circles, the centres of which must be so located as to make the tooth of the required form, and the mechanism by which this is accomplished is shown diagrammatically by Fig. 272, and by the side-view drawing, Fig. 270. The two tool slides have extensions or arms, *HH'*, the extremities of which take the form of slotted arcs and are graduated. By means of studs and nuts arranged as shown, these arcs are attached to plates that carry studs, *II'*, and these studs pass through blocks that slide freely within the guides *JJ'*, which guides are connected together by links, as shown, in such a manner that when these links are moved, the guides approach or recede from each other, but always remain parallel; exactly the same as the two blades of a parallel ruler. The links that join the two guides are all pivoted at points upon a line, *KLM*, which, as will be observed, is a continuation of the main centre line before referred to, and the middle one of the three links extends from one guide to the other; having attached to it, at the point *N*, the connecting rod *O*, by which this link, and consequently, of course, the others as well, is rotated to make the guides *JJ'* approach or recede from each other. And as the guides do this, it is, of course, evident that the curvature of the tooth outline produced will depend upon the rate at which they separate, or rather upon the ratio existing between this rate of separation and the feed of the tools into the blank.

As the head carrying the blank-holding spindle is swung around on the bed of the machine for the feed, it moves with it the circular sliding bar *P*, which, near one end, is cut with gear teeth that engage with the sector *Q*, and this sector, through the medium of bevel gears, moves a slotted lever arm *R*, to which the connecting rod *O* is attached; this arm being also graduated, so that the movement given to the lever *R*, and consequently to the guides *J* and *J'*, may be varied with respect to the feed within certain limits. It is this latter adjustment which provides for the difference in radius of curvature between

the teeth of two mating gears of different sizes; such an adjustment being in fact not needed where all the gears cut are mitres —*i. e.*, pairs of the same size. The radius of the tooth curve is always one-fourth of the radius of the pitch circle. All necessary graduations are provided for setting the machine, and the guides, moved in this manner, recede from each other as the tool goes deeper, at just such a rate as makes the tools, which are thus also separated a little further each time the feed takes place, produce the proper form of tooth.

To set this machine up for planing a given gear seems like a good deal of a job, because there are so many graduated arcs, etc., that must be carefully set; but a table is provided for doing this, and when the machine once starts to work, it cuts rapidly, because two tools are working, and, of course, the machine is automatic, the feed being also automatically released when the tools have planed to the required depth.

For some reason I failed to secure from the builders of the machine drawings and other material asked for, and am therefore indebted to *The Engineer* for the engravings of the drawings. I considered it better to thus obtain the desired material than to leave out a machine which seems to possess considerable interest.

The Gleason Machine.

The bevel-gear planing machine which has been most widely used here in America is known as the Gleason machine, made by the Gleason Tool Company, of Rochester, N. Y. The latest form of this machine, fully automatic, was exhibited at Paris, and is shown at Figs. 273 and 274, by which it will be seen that there is the usual head for the work-carrying spindle, or arbor, which last is horizontal, and the head itself can be moved back and forth upon the bed to accommodate gears of various proportions or those having hubs of unusual length. There is also a clear space in front of the blank, so that where a hub happens to extend beyond the apex of the gear itself, the machine is still able to handle such a gear. On the spindle which holds the work there is the usual master wheel by which the divisions are made, and this is turned automatically at the proper times by a friction-driven indexing mechanism in the usual manner. On the bed of the machine rests a plate or saddle, which is pivoted to swing in a horizontal plane about a centre over which the

apex of the pitch cone of the gear to be cut is placed by adjustment to position, and the feed motion swings this plate inwards about this centre to the required tooth depth; the feed being continuous, excepting when the tool is at the full depth of the tooth, when it pauses for an extra stroke before returning. A tool-carrying head reciprocates upon a slide mounted upon the saddle referred to, and is moved by a crank and connection best

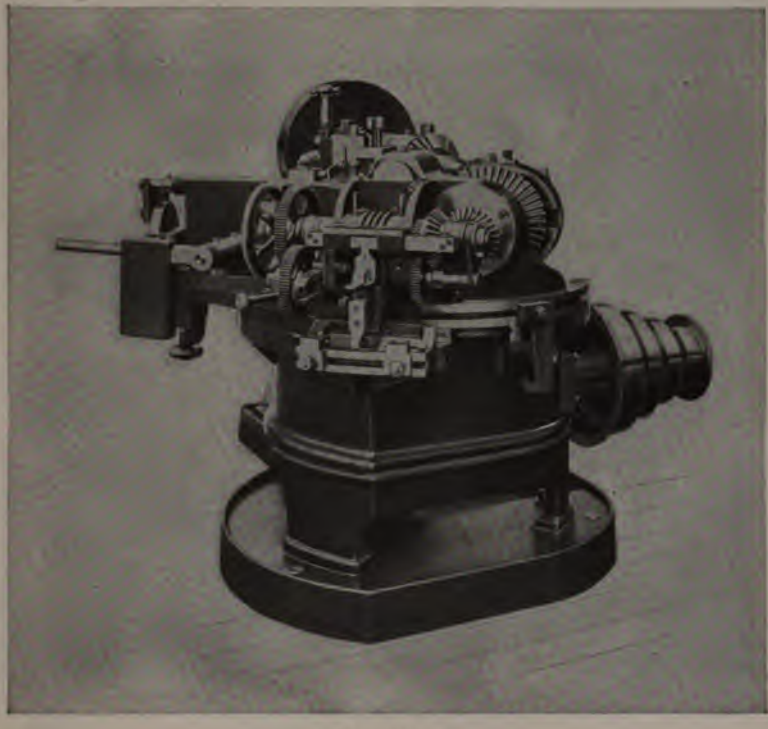


FIG. 273.

seen in Fig. 274. This slide not only has the swinging motion in a horizontal plane given to it by the feed motion already referred to, but it also swings in a vertical plane about a centre which intersects the other centre lines, and this vertical swinging motion is controlled by the former in the manner shown clearly in both photographs; a roller, attached to the arm, resting on top of the former. A former is required for each side of the tooth of the gear, and both these, together with a straight former, which is used in "stocking out" gears from the solid

blanks, are mounted upon a plate of triangular form, as seen in Fig. 274, and which is pivoted at its centre so that the required former can be brought into correct position very readily. The other mechanism is for automatically returning the tool to the top of a tooth space at a rapid rate, indexing the blank and again starting the feed motion, all of which goes on without attention until the wheel is finished and the machine automatic-

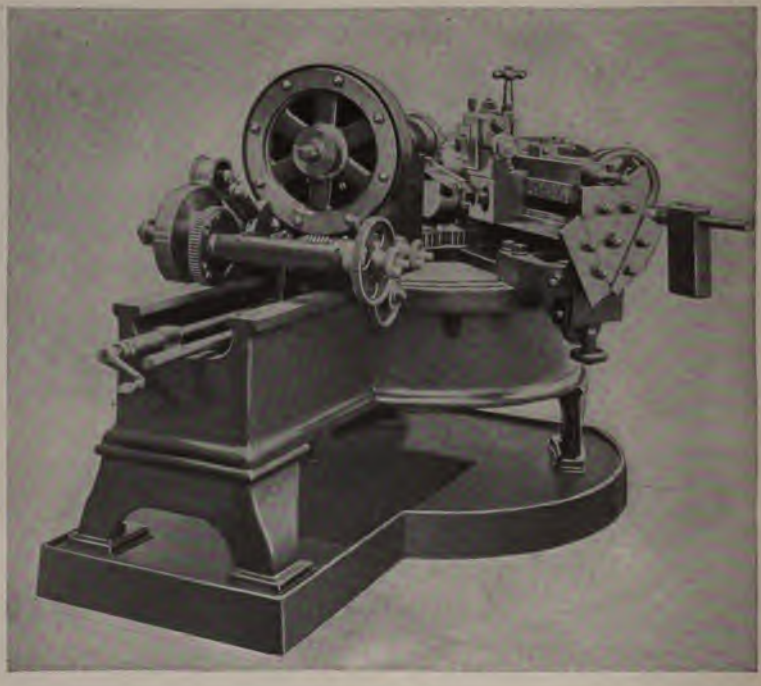


Fig. 274.

ally stops itself. These machines are, of course, built in a variety of sizes, but the one shown is called the 24-inch machine, and is for planing gears as coarse as $1\frac{1}{2}$ diametrical pitch in cast iron, or 2 diametrical pitch in steel, although it is best adapted to gears of 4 diametrical pitch in both cast iron and steel. By the use of the regular formers for the gear teeth, it will plane pairs of gears with ratios up to 1:8, and with special formers to any required ratio, its range of angle not being limited between 0 and 90 degrees. A notable feature of the machine is its stiffness and apparently heavy proportions in all parts

considering the character of the cuts it is expected to take, and this is considered to be important in order that the results provided for in the theory of the machine may be as nearly as possible actually realized in the gears cut by it.

Fig. 275 shows a group of tools used in connection with the machine. These consist of a gauge for setting the tools in the machine at the proper height, and three different planing tools, the one at the left being a double-faced tool for blocking out blanks from the solid, and which is fed straight into its cut by the straight former seen in Fig. 274, while the other two are for the two sides of the tooth space, the cut with these being taken

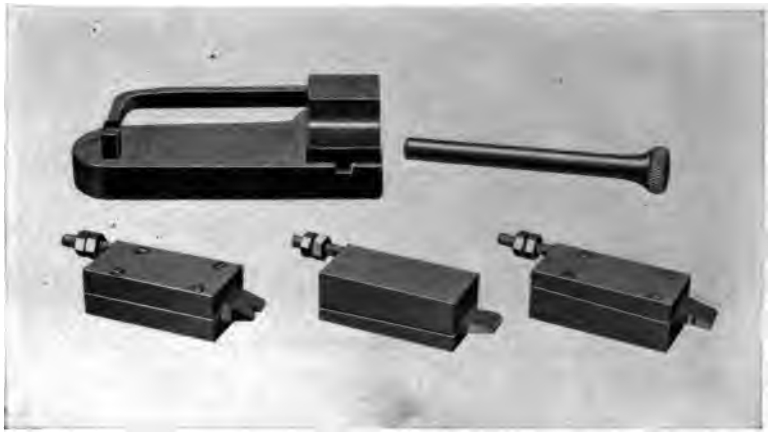


FIG. 275.

as shown at Fig. 276 by the end of the tool, the corner of which is rounded to the radius of the clearance curve at the bottom of the tooth.

The generally accepted way of following a former is to have the knife-edge rider bear upon it, in which case the former is, of course, an exact enlarged outline of the tooth. By the use of a roller the life of the formers is preserved indefinitely, but when a roller is used the formers are not an exact enlarged outline of the tooth curve, as may be seen in Fig. 277, where the path the centre of the roller describes is the true curve, but the formers are a corrected curve generated by the cylindrical surface of the roller.

The objections which have been urged against all machines which depend upon a former to give the shape of the tooth are well

known, and prominent among them is the fact that most formers are themselves inaccurate; being usually laid out with compasses or templates and then shaped finally by filing. Recently the Gleason Company has designed machines for generating these tooth templates, and though these machines were not shown at

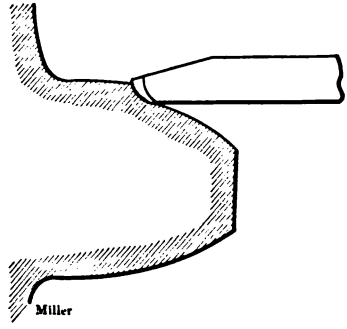


FIG. 276.

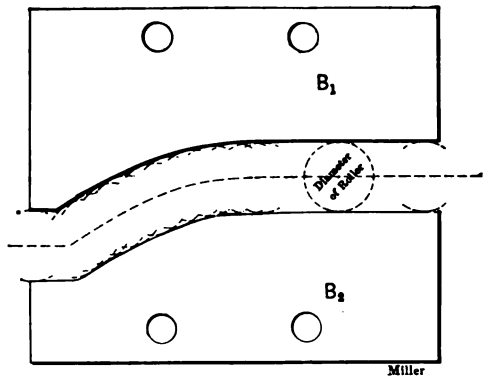
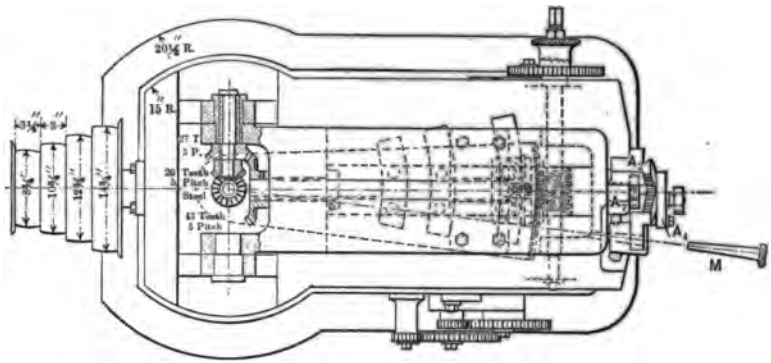


FIG. 277.

Paris, and in fact have been completed so recently that they could not have been shown there, they, nevertheless, are a part of the subject and really stand behind the machine itself and its work in such an important relation as to make their presentation in connection with it not only justifiable, but necessary in order to understand the gear-planing machine itself. They show how the objection referred to has, by this company at least, been overcome.

Machine for Generating Tooth-formers for Planing the Bevel-pinion Teeth.

Figs. 278, 279, 280, and 281 show a machine designed by the Gleason Tool Company for making formers for the teeth of bevel pinions. Fig. 279 is a side elevation of the machine showing the formers B_1 and B_2 in position to be acted upon by the milling cutter E_4. The formers B_2 and B_1 are for the top and bottom sides of the tooth respectively, and they occupy a position in this former-generating machine the same distance from the centre O of the machine that they afterward occupy in the gear-planing machine. The cylindrical milling cutter is the same diameter as the guide roller on the end of the arm of the

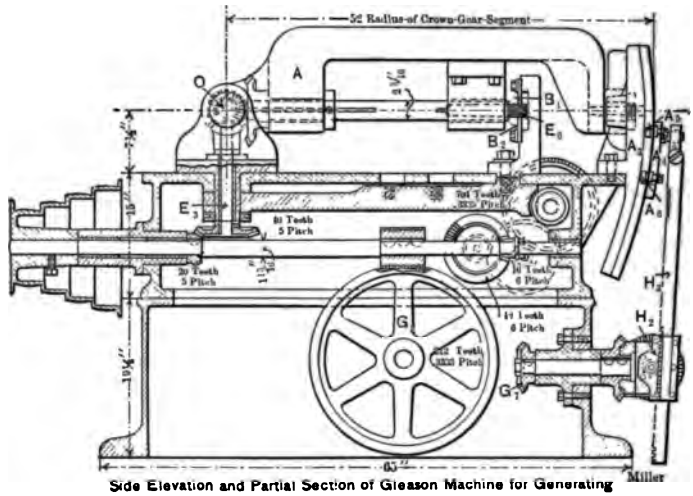


Plan and Partial Section of Gleason Machine for Generating Bevel-Pinion Tooth-Templets

FIG. 278.

gear-planing machine, and it occupies the same relative position in the former-generating machine that the roller does in the gear planer. This mill is driven from the belt cone by means of the shafts and bevel gears, as can be easily followed in the drawings, the short vertical shaft E_3 passing up through the centre of the machine, about which all the principal motions take place.

The part E (Figs. 278, 279, and 280) turns in a horizontal plane about the centre of the machine. The overhead arm A turns in a vertical plane about the centre O, while at the same time it, of course, has the same motion in a horizontal plane as has arm A, the motions of this bar being in fact identical with the motions



Side Elevation and Partial Section of Gleason Machine for Generating Bevel-Pinion Tooth-Templets.

FIG. 279.

of the bar or slide that carries the cutting tool in the gear planer.

On the end of bar A is turned a trunnion A_7, Fig. 278, the centre line of this trunnion being a continuation of the centre line of the milling cutter, which also passes through the centre O of the machine. On this trunnion is fitted, to rotate freely, the segment of a crown gear, A_5, Figs. 278 and 281, the centre line of the trunnion A_7 passing tangent to the pitch surface of the crown gear.

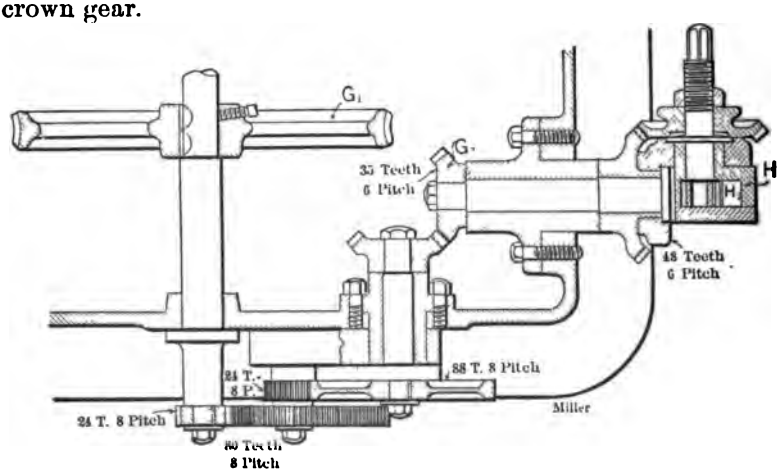


FIG. 280.

A_3, Figs. 279 and 281, is a segment of a bevel gear bolted fast to the frame of the machine. With this segment of a bevel gear the crown-gear segment engages, the two being held together by means of a sliding block A_1 which passes around the back of each. This block A_4 is moved from one end to the other end of the stationary segment A_3, thus causing the crown gear A_2 to

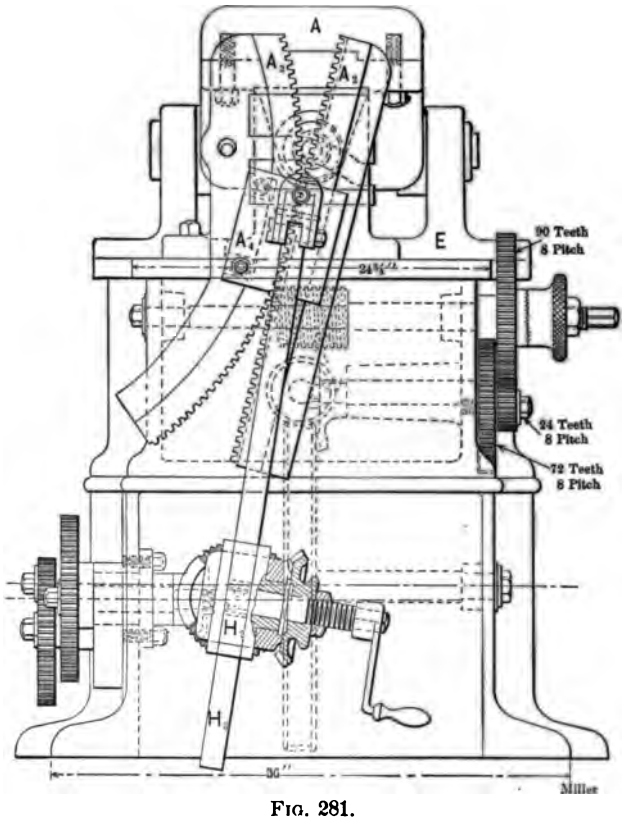


FIG. 281.

rotate around the segment of the bevel gear. A pair of rollers, A_5 and A_6, Fig. 279, are fastened to the block and act as gibs to hold it in its place. They roll on a conical surface on the back of segment A_3, which surface is turned in the lathe radial with the cone centre of the segment gear. The surface back of the crown gear is turned at a sharp angle, so that the block will hold to its place.

The crown gear being fastened to and rotating on a trunnion

turned on the end of the bar *A*, it will readily be seen that the centre of the cylindrical milling cutter will describe a true spherical involute when the slide travels up the backs of the two segments and thus rotates the crown gear around the stationary bevel-gear segment. The pitch line of the bevel-gear segment is the base line on which the pitch line of the crown gear rolls. The Gleason Tool Company use a $14\frac{1}{2}$-degree involute on their standard formers, and the radius of the bevel-gear segment is made to correspond.

When the crown gear has rolled a sufficient distance around the bevel-gear segment to allow the milling cutter to complete the spherical involute curve, then a taper pin *M*, Fig. 278, is inserted, which binds the radial bar *A* fast to the stationary segment. Then the axis of the milling cutter is in a position tangent to the pitch cone of the generating circle, and an auxiliary feed is thrown in which mills off the straight part of the form below the curve, as seen in Fig. 277. When this auxiliary feed is thrown in the formers feed past the mill in a horizontal plane, the mill rotating in a fixed position.

Of course, it is necessary to have a series of bevel-gear segments in order to make a complete list of formers for all angles.

The feed works are shown at Fig. 280, and will be readily comprehensible from it.

Machine for Generating the Formers for Planing the Gear Teeth.

If both the gear former and the pinion former were made by the process just described, the result would be a great deal of interference between the flank of the pinion tooth and the face of the gear tooth. For this reason the pinion former only is made in the machine described, and then, using this pinion former as a pattern, it is placed in another machine, as shown at Figs. 282, 283, and 284. The former that has been made for the pinion is shown at Q_2, Fig. 283, and the construction is such that the former for the mating gear is rolled around the pinion former, but with a milling cutter (representing the guide roller) between them, or rather so that it rests upon the pinion former and mills the gear former.

The figures show how a radial arm P_1 carries the cutter spindle and milling cutter. At the extreme end of the mill is a free-turning roller, which rests on the pinion template, as shown.

The radial arm P_1, Figs. 282 and 283, has a short oscillating motion imparted to it through the connecting rod T, in which motion the roller P_5 follows the curve of the pinion former. The radial bar or arm P has two motions, one in a horizontal plane and one in a vertical plane about the centre O, and its outer end is bored out in line with this centre. In this bored hole in the end of the bar there is fitted, to rotate freely, a casting P_6, Fig. 283, and the inner end of this casting carries the gear-tooth former Q_3 to be milled. To the outer end of this casting P_6 is keyed a segment of a bevel gear R_2, Figs. 280 and

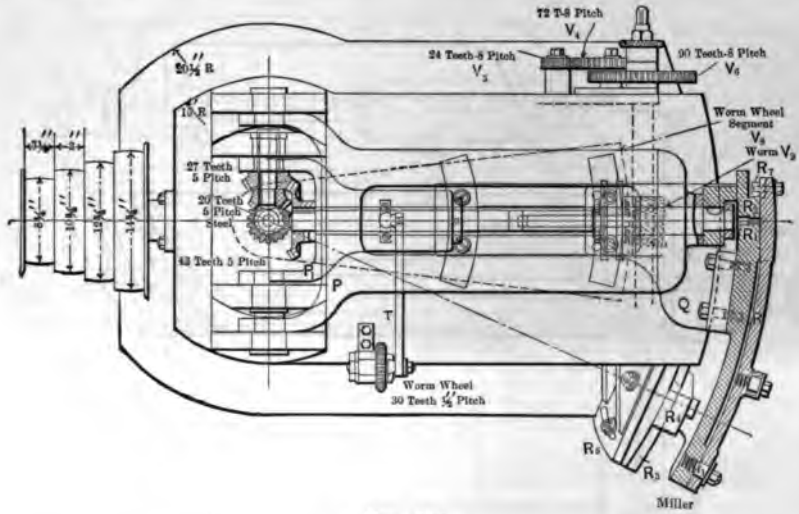


FIG. 282.

284. The pitch-line angle of this bevel-gear segment must be the same as the pitch-line angle of the gear for which the former to be milled is intended.

The pattern former Q_2, Fig. 283, is fed in a horizontal plane around the centre O. As seen in Fig. 283, the casting Q, which carries the pattern former and former holder, is bolted to a worm-wheel segment, which segment is made to rotate around the centre of the machine in a horizontal plane.

The former holder Q_1 is bolted to the casting Q, and at the outer end of casting Q is bolted fast a bevel-gear segment R_1, Figs. 282 and 284. The bevel-gear segment R_2 rotates on the end of the radial bar P, meshes with the bevel-gear segment R_1, which has the same pitch-line angle as the pinion for which the

pattern former Q_2 is intended. At the centre r_1 of the bevel-gear segment R_1 an arm is pivoted. This arm passes around the back of the bevel-gear segment R_2, and by means of the conical rollers R_7, Fig. 282, serves to hold the bevel-gear segment R_2 in mesh with segment R_1.

Bolted to the frame of the machine is a plate R_6, and to this plate is bolted a circular slide R_5, on which moves the circular sliding block R_4. The working surfaces of these slides are all turned in the lathe so that the slide R^4, when it travels, moves

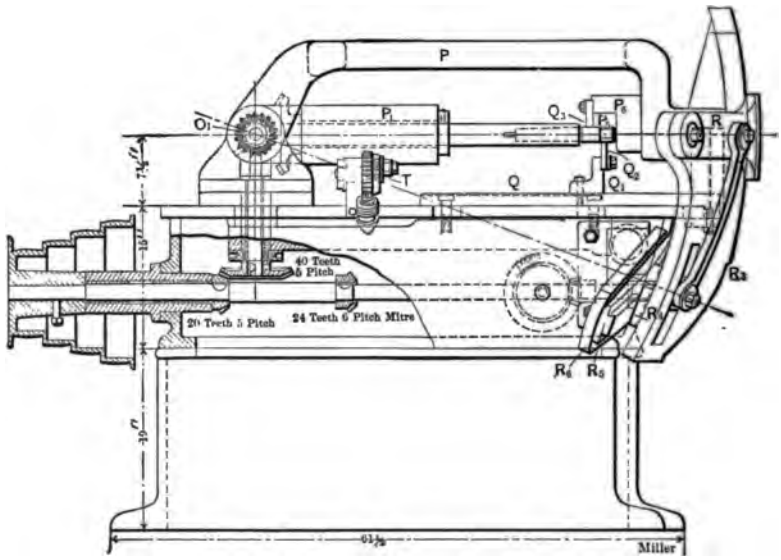


Fig. 283.

in the arc of a circle the centre of which intersects the main centre of the machine, or, in other words, its path may be said to be along the element of a sphere having its centre at O_1.

The slide R_4 is connected to the arm R by the connecting rod R_3 and a rectangular sliding block constrained to move in a vertical arc of a circle, as shown in Figs. 283 and 284, the centre of this last-mentioned arc being also at O_1.

The operation of the machine is as follows: The plate Q carrying the pattern former is fed in a horizontal plane around the centre of the machine. The slide R_5 is inclined to the horizontal plane and held stationary so that when the casting Q, which carries the bevel-gear segments, advances, the arm R

is turned about its centre by the connections, as shown. This causes the bevel-gear segment R_2, which is attached to casting P_c, and which in turn carries the former to be milled, to rotate around the segment R_1.

The radial arm P_1, which carries the milling cutter, has two rotary motions about the centre O_1 of the machine, one vertical and one horizontal, its vertical motion being independent of the vertical motion of radial bar P, so that the milling cutter is free to follow the curve of the pattern or pinion-tooth former, while both the cutter and arm P have the same horizontal motion.

The short oscillating motion of the cutter is necessary in order that the cutting mill will fully cover the point of contact

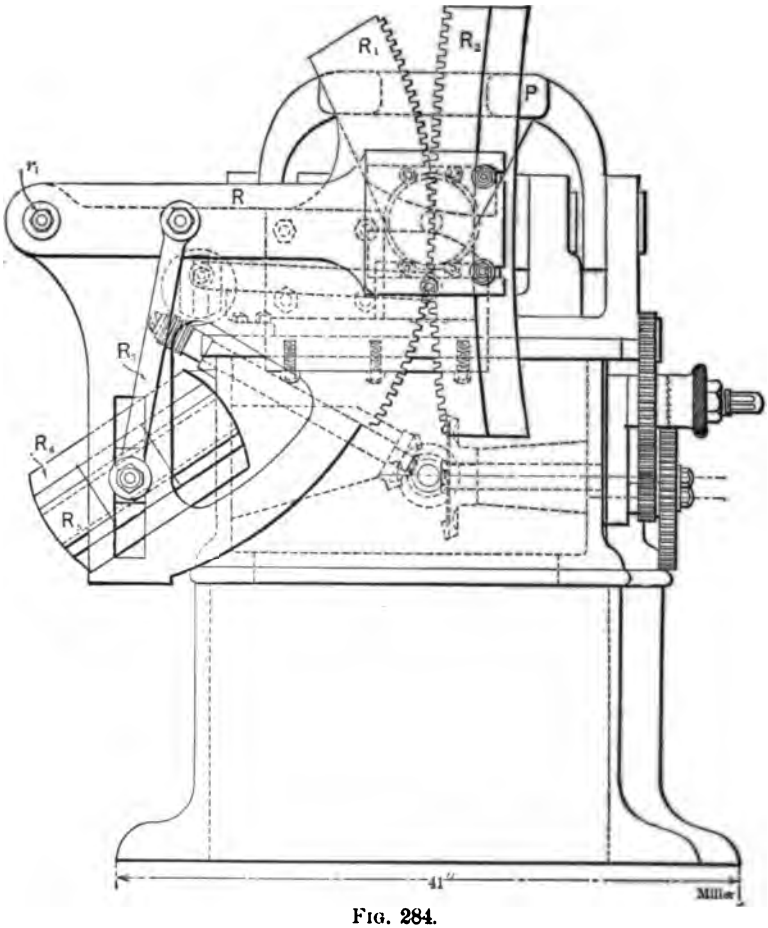


FIG. 284.

between the two curves. This point of contact does not travel at a regular rate, but when the two formers are rolled together as described, its path is fully covered by the short oscillating motion of the mill.

No appreciable errors have been discovered in the formers thus generated, and it is obviously only a matter of careful and conscientious workmanship to make thus the teeth of bevel wheels well within any ordinary requirements as to accuracy of form.

The Rice Machine.

The requirements of American bicycle manufacturers have led to the development of a number of very interesting machines for the production of such bevel gears as are used in that work, and one of these machines was exhibited in the American machinery building, at the Vincennes Annex to the Exposition. Its inventor is C. D. Rice, who, at the time he was working upon it, was master mechanic of the Pope Manufacturing Company's factory, at Hartford.

This machine is to be classed as of the template variety, since it does not generate tooth curves, but reproduces those with which it is supplied, though, of course, on a reduced scale. The template is itself a complete master gear, those in use up to the present time having been made by Mr. Bilgram, on his well-known generating machine, so that the resulting tooth curves produced by the machine are, in reality, generated curves, and as the master, or template, gear is of about five times the dimensions of the gear made from it by this machine, the errors in the gears made are correspondingly reduced from that of the master.

The principle of the machine is best shown in the model, Fig. 285, which has been made for this purpose. The large master gear is at the right, mounted upon the outer end of a horizontal axis, and the gear to be made (already gashed) is upon the inner end of the same axis. This axis is mounted upon a swinging arm, which may oscillate in a horizontal plane. The cutter—represented by a large disk—is mounted upon a second, but fixed horizontal axis, and is represented as having entered one of the gashes. A fixed stop, called the guide plate, enters a space between the teeth of the master gear. The acting face of the guide plate is in a true plane with the acting face of the

cutter, and this plane contains also the apex of the pitch cone and the axis of the vertical shaft. It is plain that if the tooth of the master gear be held in contact with the guide plate, and if, while kept in such contact, the swinging arm be swung bodily from the observer, both master gear and the gear to be cut will have a double motion, combined of the swinging motion of the arm and a turning motion about their common axis, and during this motion the cutter will obviously reproduce on the blank, and upon a reduced scale, the curves of the master-gear tooth. Stepping from tooth to tooth, one side of all teeth is soon completed, when the cutter must be adjusted parallel with its axis

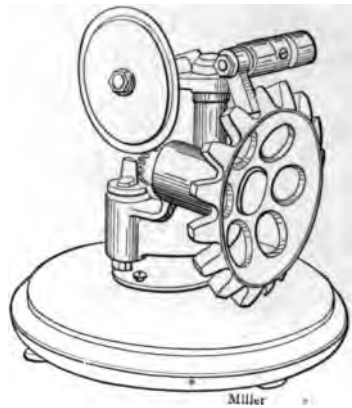


FIG. 285.

an amount equal to its own thickness, and the guide plate must be correspondingly adjusted an amount equal to its thickness, when the opposite sides of the teeth may be cut by the reverse motion of the swinging arm. Since the cutter does not travel lengthwise of the tooth being cut, the resulting space is, of course, cut slightly deeper at its centre than at its ends. To reduce this to an unobjectionable amount, the cutter is made of large diameter, as shown. It will be understood that the acting face of the cutter being a true plane, the extra depth of the cut at the centre has no effect on the acting portion of the tooth curve.

Fig. 286 shows the machine built around this simple principle. The master gear, the guide plate, the cutter, the work, and the swinging frame will be readily recognized. The mechanism added is simply that necessary to make the action automatic.

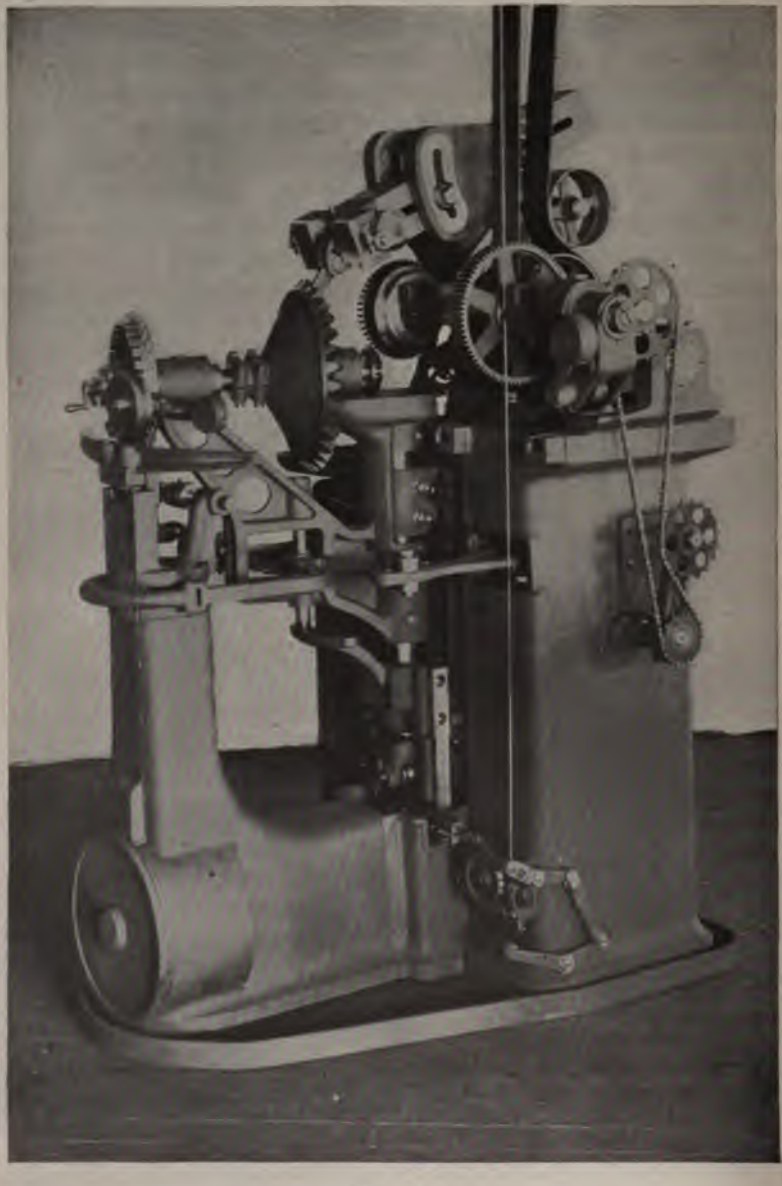


FIG. 286.

An index plate will be seen at the left, but the purpose of this is merely to insure the entering of the guide plate in the master-gear spaces as the swinging arm is raised to position for each cut. Once this is accomplished, the index plate is disengaged and the master gear has full control throughout the cutting operation; that is to say, the master governs the tooth spacing, the tooth thickness, and the tooth form, and as all gears have a working mate, it follows that by giving each pair of master gears a practical running test as to smoothness of action, treating them, if necessary, to improve their behavior, passing upon the master gear, practically inspects all work that is to be done from it, as, allowing that the machine is perfectly adjusted under its well-established requirements, each specimen of the work must be a duplicate of its master, with the errors reduced in the ratio of their diameters.

The weighted arm which maintains contact between guide plate and master-gear tooth will be seen at the left, projecting toward the observer. On it is a roller, which acts also as a weight, and below it is a curved T-shaped arm *A*, Fig. 288, rising from the standard below. Connecting this standard with the main frame casting is a frame member within which is a shaft *e*, Fig. 287. A cam *f* on this shaft, directly below the vertical spindle of the swinging arm, lifts and drops this spindle, the swinging frame and the parts which it carries. A cam *i* on the outer end of the same shaft lifts and drops the T-arm *A*, and another, *j*, alongside attends to the indexing movement. After the indexing movement the swinging arm first rises rapidly and carries the blank nearly to position for correct depth of tooth space, when the motion slows down to a feeding motion, which carries the blank to correct depthing position. During the operation of cutting to depth the arm *A* ceases to rise, which causes a slight rotative movement of the work spindle on account of the swinging arm continuing its lift during this depth feed cut, so that when the cutters have reached the bottom of the cut the sidewise action has been sufficient to insure contact between the guide plate and a tooth of the master wheel. The downward movement of the T-arm therefore gives the controlling weight full sway during the development of the tooth curve, causing the master gear to turn until stopped by the guide plate, and the swinging motion sets in—the weighted arm insuring constant contact between master gear and guide plate.

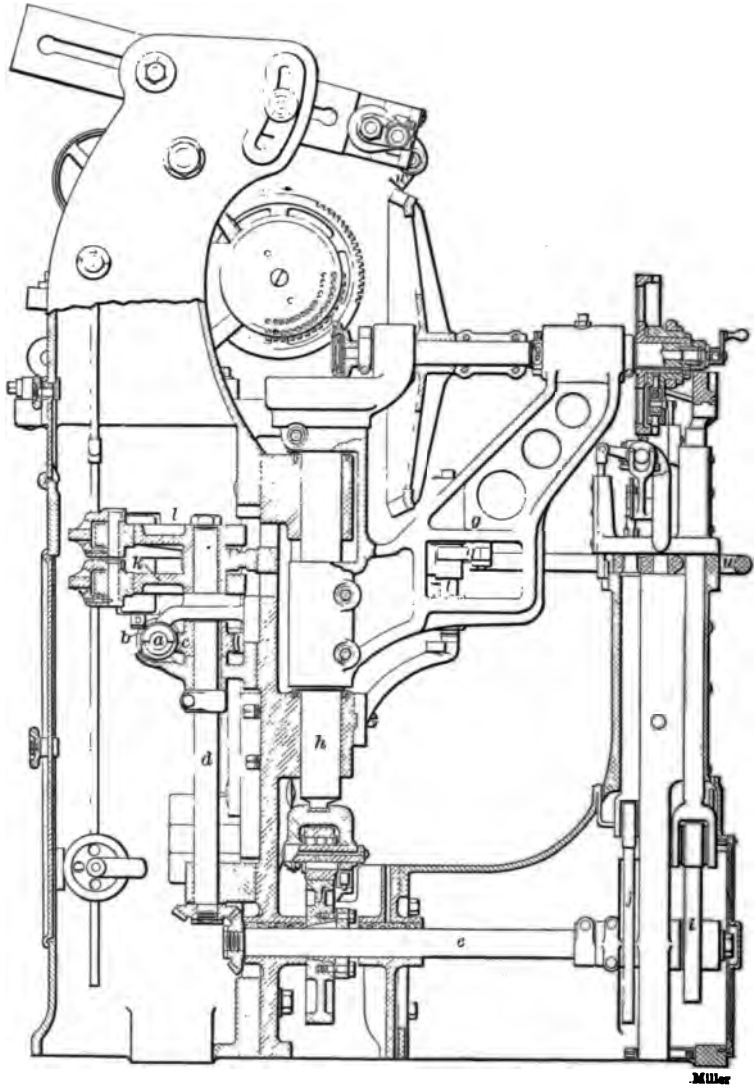


FIG. 287.

The cut completed, the swinging arm reverses its motion. During this motion the weighted arm could readily be lifted by the guide plate acting on the master-gear tooth, but this might cause unnecessary wear, and by a precautionary refinement the arm A is lifted rapidly enough to engage the roller weight and relieve the master-gear tooth from the pressure of the guide plate during the return motion.

Reference to Fig. 286 will show a pitch chain for driving a sprocket wheel on the side of the main frame. This sprocket wheel drives shaft *a*, Fig. 287, which through worm *b* and worm wheel *c* drives the vertical shaft *d*. Through the bevel gears below, shaft *d* drives, in turn, shaft *e*, on which cam *f* elevates the swinging frame *g* through the vertical spindle *h*. As the parts to be handled by cam *f* are quite heavy, the cam roller is fitted with a roller bearing, which has proven very satisfactory. At *k*, *l*, on the vertical shaft *d*, are two cams which operate the triangular levers *m*, *n* of Fig. 289. Each of these levers connects with a link *o*, *p* at its outer end, these links having jaws *q*, *r* which engage with a block *s* surrounding the pin *t*, which is located in the swinging frame *g*. The action of these connections is obviously to accomplish the swinging motion. The connections upon one side accomplish the motion for one side of the teeth, and those upon the other for the opposite side. After completing one side of all the teeth the machine automatically stops and the attendant reverses this connection through the segmental hand wheel *u*, which is so connected to the jaw ends as to disengage one jaw and engage the other by the same movement.

At this reversal the weighted swinging arm *v*, Fig. 288, is also swung over to the opposite side by the attendant, and the guide plate and cutter head are shifted by an amount equal to their own thickness, as has already been stated, these latter changes being also made by hand. Reference to Fig. 288 will show that the guide plate *w* is mounted on a block *x*, which may freely slide endwise between the micrometer stop screws *y*, *y*. These screws being adjusted to permit a movement equal to the thickness of the guide plate, the pressure of the master-gear teeth accomplishes the movement.

The starting and stopping mechanism consists of a simple disk or ratchet *z*, Fig. 288, having as many notches as there are teeth in the work, there being a trip or release pin at a certain point in this ratchet which will release the engagement and thereby allow the overhead spring connected with the countershaft to disengage the friction-clutch pulley when the circle is completed. As the machine is universal as to angle and pitch, as well as diameter, it is simply necessary, when an increased amount of stock is to be removed in coarser pitches, to slow down the cam movement, and yet permit the cutters to maintain

their same speed ratio. This is readily accomplished by placing sprockets of varying dimensions on the worm shaft *a*, Fig. 287, the slack of the chain due to these changes being cared for by an idler which swings over the bearing that carries this shaft. Mr. Rice is, I should say, now developing a machine more especially adapted to that class of bevel-gear cutting in which more

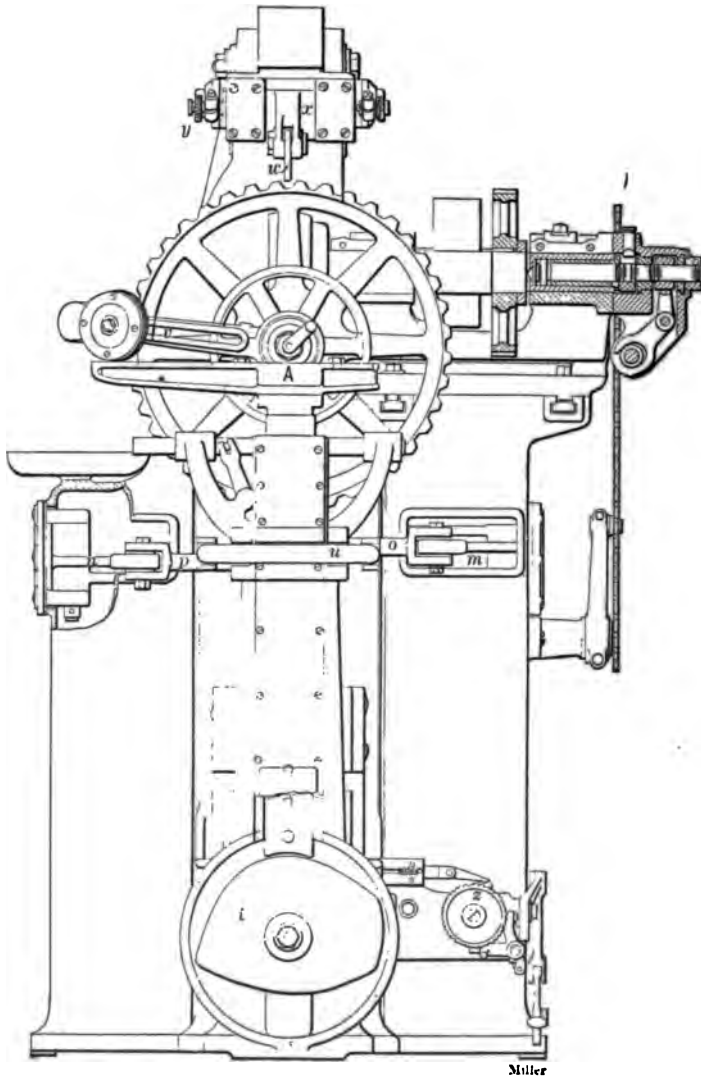


FIG. 288.

frequent changes than are necessary in making gears for bicycles are required; the intention being, in this later machine, to use only one tooth of the master gear, and to use this only to give the form to the tooth being cut, the indexing being done by separate indexing mechanism, and the object being to provide a machine adapted more especially for general use.

This machine, like the Gleason machine previously described, requires that the utmost care be given to accuracy of construc-

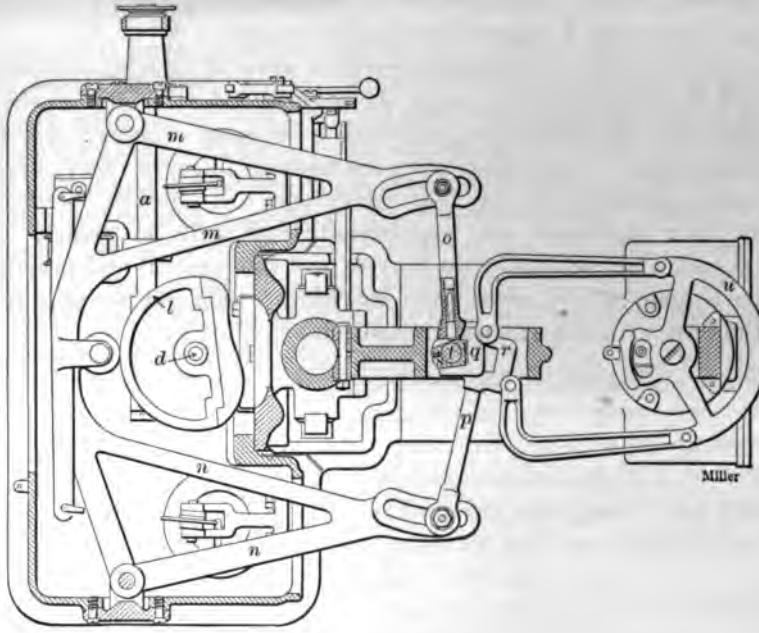


FIG. 289.

tion, and a very great degree of refinement has been reached in this regard, especially in the making of the cutters and in making sure that the action of the machine shall be precisely as intended by its designer. A description of these methods would, however, considerably add to the length of a paper which is perhaps already too long, but the length of which may, I hope, be pardoned in view of the fact that I have undertaken to describe all the machines shown at Paris which employ distinctly new methods of cutting bevel-gear teeth.

DISCUSSION.

Mr. Ambrose Swasey.—This paper is extremely interesting, inasmuch as it gives a full description of a very important line of machine tools, and I think our Society is to be congratulated upon having such a complete record of the bevel-gear-cutting engines which were exhibited at the Paris Exposition. Mr. Miller has covered the ground so thoroughly I do not know that I can add anything more which will be of interest. I will say, however, that in looking over these machines during my visit to the Exposition I was struck with two points.

Some of the machines referred to were of admirable design, and the workmanship was of the highest order; while in others, although the principles embodied were most excellent, yet the design and workmanship were not such as to carry out the principles embodied to the best advantage. No doubt, however, as later machines are constructed they will be greatly improved, and eventually we may expect some useful and practical bevel-gear cutters, even from machines which did not appear to the best advantage at the Exposition.

No. 898.*

A FEW INSTRUMENTS OF PRECISION AT THE PARIS EXPOSITION OF 1900.

BY WILLIAM E. REED, CLEVELAND, OHIO.
(Member of the Society.)

ONE of the unique features of the Paris Exposition of 1900 was the organization of retrospective or historical exhibits in various French sections. It was a feature particularly appropriate to an exposition held, as this one was, during the last year of a most eventful century, and one which placed men under obligation to the generous thoughtfulness of a warm-hearted and painstaking people, who thus commendably honored the pioneers in many branches, as at the close of the century the world came together to admire the achievements which their earlier conceptions heralded.

So it was that the French instruments of precision on the Champ de Mars were most appropriately surrounded by well-ordered groupings of strangely conceived and curiously ornamented old microscopes and telescopes and sextants and reading glasses, the interesting beginnings of years ago, from which have come by steady development the scientific instruments of to-day; the indispensable allies of research, invention, discovery.

As would naturally be expected, the exhibits of the French makers of instruments of precision, both in number and size, were larger than those from any other country, but there was much repetition and similarity in these sections. There were, for instance, many exhibits of opera glasses and aneroids, and thermometers, and hygrometers, and anemometers, but that which was strikingly new was rather to be searched for than to be easily found. There were a large number of three and four inch telescopes made in brass, highly polished and lacquered, but with little evidence of real improvement in design over the models of years ago.

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* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

Conspicuous in this section was an eighteen-inch telescope from the works of Monsieur Gautier. The workmanship was excellent, and the finish of the brass work such as it is difficult to get in America, but the general design of the instrument, at least from a Yankee standpoint, was not above criticism. The widely tapering tubes for an objective of comparatively short focus were brought into a clumsy cubical centre-piece, and, though rather heavy, the tube was supported by comparatively small axes. The column was large and out of proportion to the work required of it. The clock, too, which was excellently well made, was gross, and gave one the impression of the use of overmuch metal in its construction. In fact, one missed the many contrivances which mean so much to the operator in the ease and convenience with which he can manipulate the instrument.

Near by was a smaller telescope made for the Observatory at Athens, an instrument with twin tubes of equal diameter, one tube being arranged with photographic lens and the necessary camera outfits, and the other with visual objectives and a micrometer of excellent design, thus giving the observer his visual and photographic telescopes in such way that either was always ready for use, and that without the necessity of awkward changes from one to the other.

It was not in this section, but in a special building quite by itself, though not far away, that the great telescope of the Exposition was to be seen. The idea of making this instrument to rival any previously constructed was the conception of Monsieur Deloncle, and the design and execution of the plans were the work of the eminent engineer Monsieur P. Gautier.

Speaking generally, the instrument consisted of a great stationary telescope and a large movable mirror. The building in which these parts were mounted was designed expressly for the purpose and consisted of several apartments, chief among which were a large auditorium, and a well-designed structure for covering the mirror and its mounting, while connecting these two was a high colonnade running due north and south, in which was mounted in a stationary horizontal position the great telescope tube, its objective end turned toward the mirror, and its eye end projecting into the auditorium. The tube was 196 feet long and between four and five feet in diameter, and it rested on high masonry piers set at frequent intervals. The crown and flint disks of the photographic and visual combinations in their cells were mounted

on a special truck running on a transverse track, so that either pair of lenses could be readily put in its place in the tube as the operator might desire, while at the opposite end of the tube a truck running on a lateral track carried the eye end, which was designed for holding the usual accessories, and which was flexibly connected with the tube by a bellows to provide for properly focussing the instrument. In other respects, however, the telescope proper did not differ materially from the lens-carrying tubes of other telescopes.

The mission of the mirror to which we have already referred was to reflect the desired portion of the heavens into a telescope—that is, instead of pointing a movable telescope to the heavens, the heavens were reflected into a stationary telescope by means of a movable mirror, mounted in this case on the principle of the Foucault Siderostadt. It will be seen, therefore, that the successful working of the instrument must depend upon the accuracy of the mirror and the perfection with which, while constantly changing its position to follow the stars, it can reproduce the desired portion of the heavens into the telescope, for any errors in the reflected image would be only magnified to worse distortions by the great lens itself. The mirror was a plain silvered glass disk 6½ feet in diameter and a little over 10 inches thick. It weighed 1½ tons, and was mounted in a cell of about the same weight. The cell turned on trunnions, from which the weight was partially relieved by ingenious systems of levers and counterpoise weights, and the yoke which carried this cell, a total weight of several tons, was mounted so that it could be turned about a vertical axis, from which a great portion of the weight was relieved by floating on a mercury bath. This system of mounting, it will be observed, not only reduced greatly the power required to turn these parts, but for all practical purposes made the problem of motion as though the parts in question were of smaller mass. The yoke carrying the mirror was mounted in an enormous cast-iron base built in sections in the shape of a conventionalized letter *L*, the vertical limb of which was a column 34 feet high and curved somewhat forward. At the top of this column was mounted the polar axis of the instrument, the axis parallel to that of the earth, while the mirror and its supports were at the toe of the base. The polar axis and the mirror were flexibly connected by a clever combination of levers, gears, and sliding joints, so that motion from the driving clock, which caused the polar axis to turn round at a uni-

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DISCUSSION.

Mr. Ambrose Swasey.—This paper is extremely interesting, inasmuch as it gives a full description of a very important line of machine tools, and I think our Society is to be congratulated upon having such a complete record of the bevel-gear-cutting engines which were exhibited at the Paris Exposition. Mr. Miller has covered the ground so thoroughly I do not know that I can add anything more which will be of interest. I will say, however, that in looking over these machines during my visit to the Exposition I was struck with two points.

Some of the machines referred to were of admirable design, and the workmanship was of the highest order; while in others, although the principles embodied were most excellent, yet the design and workmanship were not such as to carry out the principles embodied to the best advantage. No doubt, however, as later machines are constructed they will be greatly improved, and eventually we may expect some useful and practical bevel-gear cutters, even from machines which did not appear to the best advantage at the Exposition.

No. 898.*

A FEW INSTRUMENTS OF PRECISION AT THE PARIS EXPOSITION OF 1900.

BY WILLIAM E. REED, CLEVELAND, OHIO.
(Member of the Society.)

ONE of the unique features of the Paris Exposition of 1900 was the organization of retrospective or historical exhibits in various French sections. It was a feature particularly appropriate to an exposition held, as this one was, during the last year of a most eventful century, and one which placed men under obligation to the generous thoughtfulness of a warm-hearted and painstaking people, who thus commendably honored the pioneers in many branches, as at the close of the century the world came together to admire the achievements which their earlier conceptions heralded.

So it was that the French instruments of precision on the Champ de Mars were most appropriately surrounded by well-ordered groupings of strangely conceived and curiously ornamented old microscopes and telescopes and sextants and reading glasses, the interesting beginnings of years ago, from which have come by steady development the scientific instruments of to-day; the indispensable allies of research, invention, discovery.

As would naturally be expected, the exhibits of the French makers of instruments of precision, both in number and size, were larger than those from any other country, but there was much repetition and similarity in these sections. There were, for instance, many exhibits of opera glasses and aneroids, and thermometers, and hygrometers, and anemometers, but that which was strikingly new was rather to be searched for than to be easily found. There were a large number of three and four inch telescopes made in brass, highly polished and lacquered, but with little evidence of real improvement in design over the models of years ago.

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* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

scope, a horizontal tube seven feet long with two objectives, both mounted on the same side of the tube, but at opposite ends, the axes of the objectives being at right angles to the axis of the tube. In the centre of the tube, and on the opposite side from the objectives were the two eye-pieces. Just inside of the objectives, prisms turned the rays of light down the tube towards the centre, and other prisms near the centre turned them out again through the eye-pieces. In this particular instance there was a magnifying power of twenty, so that, to all intents and purposes, one saw as though one's eyes had been suddenly moved apart six or seven feet, and as though the object viewed were twenty times as near. This change of the eyes to a wider base line does what the stereoscope does to the photograph, makes the objects seen—trees, knolls, groves, houses "stand out" in space, as they do not appear to do, and for obvious reasons, when seen in the comparatively flat field of an ordinary telescope. Perhaps as a practical instrument for work-a-day use this type would have limited usefulness, and yet surely that does not detract from the enjoyment of its many interesting features.

In still another instrument constructed on the same principle as the one just described, but of much smaller size, an empirical saw-tooth scale, placed within the field, enabled the observer to readily and accurately judge the distance of objects not farther away than two or three miles, for being seen through the glass, they were easily caused to come apparently into their proper place on the scale, from which the distance was read.

The space allotted to the United States for all its Liberal Arts exhibits was by no means large, and the arrangement necessitated much crowding and the close proximity of very dissimilar subjects, yet, huddled between automatic banjos, phonographs, and false teeth were some exhibits of instruments of precision which attracted no little attention. The Brown and Sharpe Manufacturing Co., of Providence, showed the delicate measuring instruments—micrometers, scales, vernier-calipers—by which the mechanician gauges accuracy. No large case was required for their exhibit in this section, but its contents, though small, represented great intrinsic value. Little wonder that men paused here, and passing, commented that this exhibit stood for the very highest standards in its lines the whole world round.

Nearby was the optical and physical exhibit of J. A. Brashear, of Allegheny, Pa., showing to within what almost inappreci-

able limits it is possible to approach perfection: Test-planes with surfaces parallel to within .00001 inch; compound prisms which, by the exceeding accuracy of their many sides, received light from a given object, reflected it, divided it, united it, and sent it forth again entirely inverted from its position on entering; speculum metal plates, prepared at the same laboratory with such exactness of surface that by Dr. Rowland's famous engine at the Johns Hopkins University diffraction gratings were ruled upon them by engraving parallel lines 15,000 to the inch both on flat and concave surfaces; spectroscopes which, both in ingenuity of design and mechanical perfection of workmanship, have gone far toward giving American astronomers important advantages in the science of astrophysics. Here, too, Warner and Swasey, of Cleveland, exhibited some of the astronomical instruments for the making of which they have become so widely known. A twelve-inch telescope appeared in decided contrast to any of the similar instruments exhibited elsewhere, by reason of the ingenuity displayed in its design and the convenience with which it could be operated. A hand wheel at the north side of the column within easy reach of the operator furnished means for turning the tube at will on the polar axis. Just above this much appreciated convenience was placed a stationary dial which by means of a pointer connected by gearing with the polar axis gave the hour circle readings, or by means of a movable dial within the one just referred to, and concentric with it, the inner dial being connected with the driving clock, true right ascension could be read by means of the same pointer. Still again, reading microscopes and prisms placed just above the dial enabled the operator to read the fine graduations on the face of the hour circle, mounted on the polar axis 110 degrees and no little distance above. At the eye end of the telescope was a unique position micrometer provided with ingenious means of securing both filar and field illumination, as well as lighting for reading the position circle verniers, the micrometer head and the revolution counter, all by means of one single incandescent electric lamp, the lamp being mounted within a metal lantern, so that the rays of light would in no wise interfere with the observations of the astronomer.

The general design of this telescope attracted much attention: a rigid but graceful column with evidence of the designer's skill even at the corners, a light, strong, stiff steel tube, the whole instrument painted and varnished—a most suitable finish for an

instrument that must be out of doors more or less, and always subjected to changable weather conditions.

On smaller instruments in this same exhibit a three-inch Combined Transit and Zenith Telescope and a two-inch Alt-azimuth, the instruments by which celestial measurements are made, were reading circles graduated on the new circular dividing engine designed and built by this company, the graduations being correct within a greater degree of accuracy than ever before obtained in circular dividing, the maximum error of the automatic graduations being within one second of arc.

A further noticeable feature in these instruments was the fact that iron and steel had been largely substituted for brass and iron, in order that temperature changes might cause the least serious disturbances.

One of the unique and strikingly new instruments which, while it hardly comes under the heading of Instruments of Precision, was none the less of a precise and delicate nature, came from the land of the much used telephone, Denmark, and was called by its inventor a recording telephone. It was not a telephone merely, nor a phonograph, nor was it a combination of these two instruments, although the result which it produced was what might be expected if two such instruments should be made to work in harmony with each other. It was designed for use in places where perchance no one might be present to receive the telephone call. The would-be speaker delivers his message as though a friendly ear were listening, and all unobserved the recorder preserves the spoken words till a listener comes, when, at his bidding, in speech audible through the receiver of the telephone, it repeats the sender's phrases. The instrument is beautifully simple; no chiseled groove of varying depth in plate or drum causes the vibrations which produce the sound, but a small steel wire, magnetized transversely, is the secret of its working. A drum four or five inches in diameter, and ten or twelve inches long, carries carefully wound on its circumference a spiral of hard bright steel wire, perhaps $\frac{3}{32}$ of one inch in diameter, and wound with a diameter's width between each loop. On a round metal rod or guide placed parallel with the axis of the drum there travels a little carriage which moves freely backward or forward, and carries with it a small double-pole electro-magnet, wound with many turns of fine insulated wire. The pole shoes are just far enough apart to fit snugly astride the wire, and they make ample

contact with it, so that this wire helix is all that is needed to cause the carriage to travel laterally when clockwork makes the drum revolve. The magnet wire is in circuit with the sending telephone, and by reason of the varying current passing through it as speech is transmitted, the magnet varies in strength and magnetizes the steel wire on the drum transversely to varying degrees of intensity. The length of the drum and its coil determine the length of the conversation; and when, as is easily arranged, the magnet is carried back to the starting point and, being placed once more in contact with the helix, the drum is again revolved, the varying intensities of the field through which the magnet passes cause the undulating current, by the well-known laws of induction, to flow once more through the fine wires of the electro-magnet and through the line setting in motion the diaphragm of the receiving telephone, till for all the world one could not tell but that one's friend were actually at the sending end, save for a mechanical persistency in speech which would not permit of interruption.

More than one repetition of the message is practicable, and when finished the magnet is once again caused to follow along the wire path, this time with an even current flowing through its spools, and the wire is demagnetized through its entire length to one and the same degree of intensity and made ready for another message.

It is with no little reluctance that we must needs finish this sketch without having mentioned still other instruments of precision, not so prominently exhibited perhaps, yet none the less worthy. But we would not impose upon your patience; and if we would, such was the wonder of the harmonious whole that sprang as by magic from the dusty confusion of those days of intense effort before the opening of the Exposition, that a sojourn such as ours, even though it lasted from that early time until yet worse confusion announced its close, was no long period in which to assure oneself that there was still no new thing to be seen. Nor would we turn from this subject without gladly recording our warm gratitude to the people of the sister republic for their Exposition of 1900, and for its rare opportunities for study, for comparison of stages in progress, and for buoyant inspiration as we turn our faces toward the future.

No. 899.*

SOME EXPERIMENTS ON BALL STEP-BEARINGS.†

C. H. BENJAMIN, CLEVELAND, OHIO.
(Member of the Society.)

MOST of the published experiments on steel balls have merely shown the crushing strength of the balls under a dead load. In service, balls do not fail in this way, and figures for the ultimate crushing strength are very misleading when used as a basis for designing bearings. Some other experiments have been made on bearings running at a moderately high speed under light loads to determine the frictional resistance. It seemed desirable to make some further experiments, which should show the behavior of steel balls when running at various speeds and under gradually increasing pressures, to measure the horse-power consumed, and to determine the manner of failure.

Some investigations of this nature were made, under the direction of the writer, by senior students of the Case School of Applied Science during the years 1899–1900. The apparatus to be described was designed and built by Messrs. Grothe and Stephan, of the class of 1899, and a few experiments made. The work was continued the next year by Messrs. Hanlon and Harper, of the class of 1900.

Some of the phenomena which developed in the course of these experiments were novel and of such interest as to warrant their publication.

The experiments so far made have been confined to thrust or step-bearings, and the apparatus used is shown in Fig. 290. The spindle A is held upright by the circular base K, which latter rests on the platform of a testing machine. On the spindle revolves the pulley B, driven by a belt from a Webber dynamo-

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† For previous discussions on this topic, consult *Transactions* as follows:

No. 820, vol. xx., p. 804: "Elevators." C. R. Pratt.

No. 841, vol. xxi., p. 351: "Strength of Steel Balls." J. F. W. Harris.

meter used to measure the power transmitted. This pulley has ball bearings above and below, precisely alike in character and size. Pressure is transmitted by the block *G* attached to the cross-head of the testing machine. The ring of balls to be tested runs between the two hardened and ground plates *C* and *D*, and is kept in place by the loose retaining rings *E* and *F*. The central well *I* is used for oiling the spindle, the radial holes *J* remove surplus oil by centrifugal force, and the packing rings *H* of vulcanized fibre prevent the oil from getting into the ball bearings.

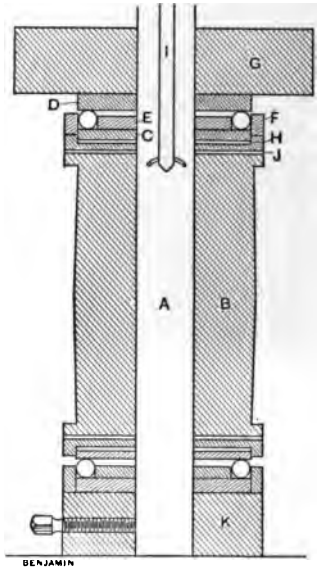


FIG. 290.

The hardened plates and the retaining rings could be changed at pleasure, and any size or number of balls used. Fig. 291 is from a photograph of the apparatus removed from the testing machine and with plates loosened to show the construction.

With this device it was possible to test step bearings with different sizes and arrangements of balls under any desired pressure, and at the same time to measure the power consumed in driving. To establish a zero reading of power, the apparatus was driven without any load on the bearings, and the horse-power noted.

In most of the experiments to be described a wooden pulley

14 inches in diameter was clamped outside the pulley *B* to give more torque.

The steel balls and the hardened plates were obtained of firms making a specialty of this kind of work. The first experiments were made with ¼-inch balls and flat plates, the speed being 375 revolutions a minute.

Fig. 291.

As the pressure on the bearing was increased it was found that the balls exerted a considerable radial pressure on the outer retaining ring *F*, Fig. 290.

Under a load of 2,000 pounds this pressure was sufficient to cut a groove in the retaining ring. When the ring was allowed to revolve freely with the balls, each ball would indent the ring; and when the ring was removed, thirty-one distinct dents could be seen at regular intervals, one for each ball.

Thinking that this might be due to springing of the plates under pressure, we made the next lot of plates slightly concave at angles of 10 minutes, 20 minutes, 30 minutes, and 40 minutes, so as to bring the pressure of the rings directly above and below the ball circles. Instead of remedying the difficulty, this made it worse, the outward pressure being greater than before.

At the speed used (375 revolutions per minute) the centrifugal force was not enough to account for the radial pressure, and the following was suggested as an explanation:

A pressure of 2,000 pounds and upward on a bearing of this size (about thirty ¼-inch balls) is probably sufficient to slightly distort the balls and change each sphere into a partial cylinder at the touching points. While of this shape it would tend to roll in a straight line or a tangent to the circle, thus pressing against the outer retaining ring.

Acting on this suggestion, we next had plates ground slightly convex, as shown in Fig. 292, the first angle tried being 20 min-

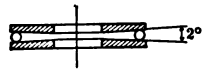


FIG. 292.

utes: 40 minutes and then 1 degree were tried, with a decided improvement in the conditions, it being possible with the last angle to increase the pressure up to 3,000 pounds without excessive friction.

An angle of 1 degree 30 minutes being tried, the radial pressure again increased. It was supposed that the angle between the plates, now 3 degrees, was sufficient to cause the balls to be wedged out against the ring.

The subsequent experiments were made with plates having each an angle of 1 degree, or 2 degrees between the plates. Circular tongs were made with which to grasp the retaining rings and determine when the radial pressure became excessive. It may be stated in general that under no circumstances was it possible to load a bearing of the size mentioned over 3,000 pounds without seriously impairing its efficiency and durability.

Now, thirty ¼-inch balls should have (according to the results of experiments on direct compression) an ultimate combined strength of about 180,000 pounds, and a safe working strength of about 36,000 pounds.

At one-twelfth of this working load the balls in such a bearing would lose all value as transmission elements. The retaining ring, when carried around by the balls, was always liable to rub against either top or bottom plate and cause abrasion and heating.

When the balls were retained in one circle, as shown in Fig. 290, the continual travel in one path soon grooved the plates

FIG. 293.

enough to injure them. One plate developed radial cracks under this treatment, probably on account of the stretching of the outer circumference by the drawing effect of the balls.

Different radii of ball circles and different sizes of balls were tried, as may be seen from the tables.

One plate was broken, as shown in Fig. 293, the circle of balls having a diameter of about 2.25 inches and the pressure being 4,000 pounds, or about 140 pounds on each $\frac{1}{4}$-inch ball. In this case the plate had evidently been overheated in hardening.

Several times balls were broken after running two or three hours under pressures varying from 3,000 to 3,500 pounds, or from 120 to 150 pounds per ¼-inch ball. The heating due to the pressure against the retaining ring was sometimes sufficient to turn the balls blue. The fractured balls, however,

FIG. 294.

showed no appearance of peeling or flaking, but were broken square across at or near a diameter. See Fig. 294.

In one series of experiments the whole space between flat plates was filled with ¼-inch balls put in indiscriminately. As

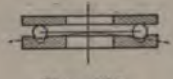


FIG. 295.

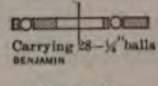


FIG. 296.

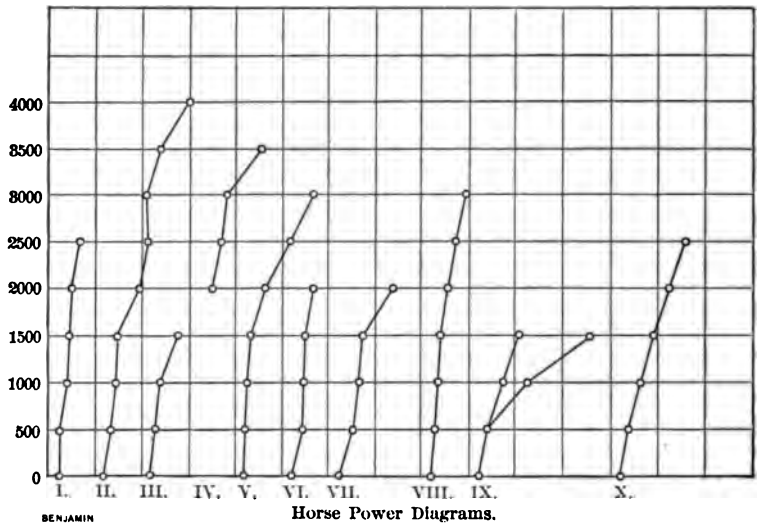
might have been expected, the friction was enormously increased by this arrangement, and the belt slipped at a load of 2,000 pounds. See IX. in tables.

The three-point bearing shown in Fig. 295 did not give as good results as the flat plates, but this was partly due to the

fact that the plates in this case were not ground. See X. in tables.

We obtained the best results with a ring cage (Fig. 296) with holes so arranged as to give each ball a different path and thus distribute the pressure and wear on the plates. As flat plates were necessary with this arrangement, considerable outward pressure occurred. See VIII. in tables.

In making the experiments from which the following tables were compiled, the balls were carefully cleaned, and although



Horse Power Diagrams.

FIG. 297.

greasy were not oiled. The usual speed was about 260 revolutions per minute and the pressure was increased by additions of 500 pounds until the belt slipped. The bearing was run for 10 minutes under each pressure.

The gross horse-power was measured for each load by the dynamometer and the friction horse-power determined by running the bearing without pressure. The spindle A was thoroughly oiled, oil flying all the time from the radial holes J (Fig. 290).

The plate, Fig. 297, shows graphically the gradual increase of horse-power with load. The double curve in the case of IX shows the extreme variation in the power due to the accidental interferences of balls when running loose without rings or cages.

TABLE.

HORSE-POWER QUOTED INCLUDES BOTH BEARINGS.

Kind of Bearing.	Load Pounds.	Gross Horse-power.	Net Horse-power.	Remarks.
I. Plates—1 degree, 27 balls, $\frac{1}{4}$ inch.	500	.1125	.0105	Plates soft.
	1,000	.195	.093	
	1,500	.204	.102	
	2,000	.238	.136	
	2,500	.332	.230	
II. Plates—1 degree; 27 balls, $\frac{1}{4}$ inch; $2\frac{3}{16}$ circle.	500	.172	.070	
	1,000	.216	.114	
	1,500	.226	.124	
	2,000	.480	.378	
	2,500	.27 to .54	.17 to .44	
	3,000	.533	.431	
	3,500	.54 to .67	.44 to .57	
	4,000	.82 to 1.0	.72 to .90	
	4,500	.....	.....	Machine stalled.
III. Plates—1 degree; 26 balls, $\frac{1}{4}$ inch.	500	.147	.045	Poor plates.
	1,000	.198	.096	
	1,500	.395	.293	
IV. Plates—1 degree; 26 balls, $\frac{1}{4}$ inch.	2,000	.257	.155	III. continued with new plates.
	2,500	.350	.248	
	3,000	.418	.316	
	3,500	.766	.664	
V. Plates—1 degree; 19 balls, $\frac{1}{4}$ inch; $1\frac{7}{32}$ circle.	500	.116	.014	
	1,000	.140	.038	
	1,500	.166	.064	
	2,000	.317	.215	
	2,500	.566	.464	
	3,000	.55 to .83	.45 to .72	
VI. Plates—1 degree; 20 balls, $\frac{3}{8}$ inch.	500	.213	.111	
	1,000	.229	.127	
	1,500	.247	.145	
	2,000	.326	.224	
VII. Plates—1 degree; 15 balls, $\frac{3}{8}$ inch.	500	.260	.158	
	1,000	.321	.319	
	1,500	.361	.259	
	2,000	.660	.558	
VIII. Plates—flat cage; 28 balls, $\frac{1}{4}$ inch.	500	.137	.035	See Figure 7.
	1,000	.177	.075	
	1,500	.198	.096	
	2,000	.278	.176	
	2,500	.354	.252	
	3,000	.472	.370	
IX. Plates—flat; 79 balls, $\frac{1}{4}$ inch.	500	.178	.076	Bearings filled with balls.
	1,000	.35 to .56	.25 to .46	
	1,500	.51 to 1.27	.41 to 1.17	
	2,000	.....	.....	Machine stalled.
X. Three-point; 18 balls, $\frac{3}{8}$ inch.	500	.185	.083	See Figure 6. Plates not ground.
	1,000	.310	.208	
	1,500	.448	.346	
	2,000	.600	.598	
	2,500	.790	.698	

No. VIII., the cage bearing, is seen to be the most uniform and the most satisfactory as regards power loss. The irregularities in most of the curves are due to the seizing of the outer ring by the balls, as before explained.

Under heavy pressures and long-continued wear a ball step-bearing is a very uncertain quantity, unless so designed as to eliminate to the greatest extent possible the outward radial pressure of the balls.

No pressure in any way approaching the crushing strength of the balls can be tolerated.

DISCUSSION.

Prof. Thomas Gray.—Professor Benjamin's paper recalls to my mind an investigation which I began about three years ago, but which is still unfinished. The objects of this investigation were the determination of the friction coefficient for balls when used in thrust bearings, and to find, if possible, what form of race would give stable running without the use of constraining rings.

The method of experiment which I adopted resembled in some respects that adopted by Professor Benjamin. Like him, I had a double set of ball races, leaving a central portion free to turn between them. The arrangement is illustrated diagrammatically in Fig. 298. A spindle S passed through three plates A, B, C, and was arranged to drive the plates A and C, but leave B free. Friction between the middle plate and the spindle was reduced by a ring of balls, as shown in the diagram. The whole rested on a plate D, which was free to turn around a ball race beneath it. The lowest plate, E, rested on a steelyard for the purpose of measuring the load on the bearings.

The pressure was applied, and the rotation produced by means of a heavy drill press, into which the spindle S fitted like a drill. The torque applied by the balls to the middle plate was measured by means of a spring dynamometer (Fig. 299), consisting of two pairs of springs applied to the opposite ends of a diameter of the plate B. This dynamometer held the plate B at rest.

The plate A was flat on top and conical on the lower side, the plate B was a hollow cone above and a convex cone below, and the plate C was a hollow cone above and flat below. The angles of the cones on the upper surfaces were made just sufficient to

cause the ball to roll toward the centre. The under surfaces were a few degrees more conical. All the plates were hardened, and the surfaces ground and polished.

The conical form of the upper surfaces was adopted for convenience after some preliminary experiments with flat plates had shown that the balls gradually increased the radius of their path. The method of experiment was to start the ring of balls either from contact with the spindle or a ring round it, and allow them to separate from the ring and from each other as the path increased in radius. This method worked well, the balls rolled

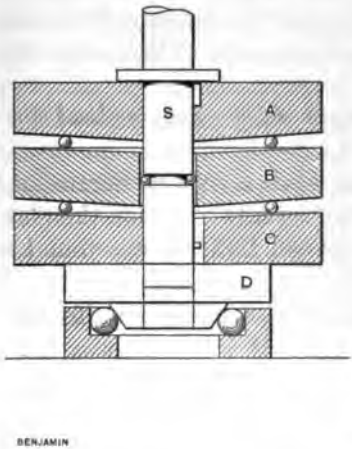


FIG. 298.

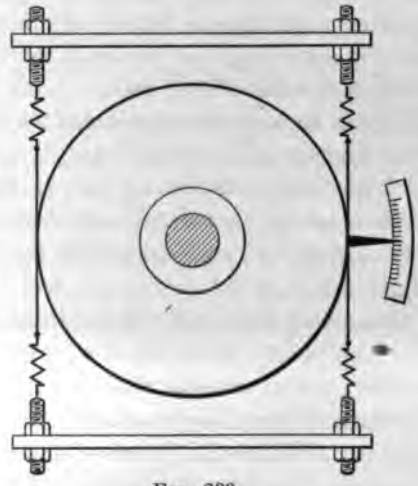


FIG. 299.

entirely free from each other, and the plates kept automatically in adjustment. The reasons for making the lower surfaces more conical than the upper were two.

The first was to allow each ball, irrespective of slight difference in size, to take automatically its own share of the load. The second was to test the following theory: Since the load on the balls causes them to roll on a ring of sensible breadth, the surfaces ought to be inclined at such an angle that the balls may roll as cones. The idea was to test whether there was a certain diameter of race on which the friction would be a minimum, and also whether, when this diameter of race was reached, the balls would continue to keep the same path. The results of the experiments indicated that if there was any stability of path it was not sufficient to overcome the tendency to slip out, due to

the wedging action of the conical surfaces; hence a very large radius would be required, so that the cone could be made flat enough.

A 6-inch plate was not sufficient for a ball $\frac{3}{16}$-inch diameter.

Some of the other results obtained may be of interest. In the first place, great difficulty was experienced in obtaining plates of sufficient hardness not to cut. The plates used were made from high-grade tool steel, such as is used for milling cutters, but sufficient hardness could not be obtained to permit a great range of load to be used. A series of experiments was, however, made within the allowable range. Each experiment consisted of a run during such time as it took the balls to move out from the spindle to the outer edge of the disk, with observation of the torque for different radii of ball race.

Each successive experiment was made with a heavier load than the preceding.

The results obtained showed that when a very moderate load was reached the torque increased very rapidly. When the plate was taken out and examined by reflected light, it was found to have a fine spiral groove pressed out on its surface, and the polish showed clouding, which resulted from a want of uniformity in hardness. This want of uniformity of hardness was made very evident during the experiment by the irregularity of the dynamometer indication after the load exceeded a certain critical value. With balls $\frac{3}{4}$ inch diameter a load of 40 pounds per ball began to damage the surface of the plate.

So long as the load was not sufficient to damage the surface, the torque was found to follow a perfectly definite law. Let p be the load per ball and r the radius of the race in inches at any instant. Then the torque T was found to be expressed by

$$T = ap^{\frac{3}{2}} + bpr,$$

where a and b are constants. For balls $\frac{3}{4}$ inch diameter, the value of a and b were found to be

$$a = 0.00043,$$
$$b = 0.00032.$$

It will be noticed that the moment of friction under these conditions is very small. Suppose the whole load to be 2,000 pounds on 20 balls. Then $T = 20 (.00043 \times 1000 + .00032 \times 100)$

= 9.24-inch pound units. When driven at 260 revolutions per minute, this would give, for a single race, 0.038 horse-power, and for the double race 0.076 horse-power. Comparing this with the results quoted in the paper, it would seem that, in Professor Benjamin's experiments, at least two-thirds of the power was absorbed by the constraining rings. The torque T is made up of two parts, the first term representing a constant pivot friction, the second the rolling friction, the torque from which is of course proportional to the radius.

It is interesting to note in this connection that when a mark was put on one of the balls and its mode of rolling observed, it was always found to keep practically a constant axis of rotation. This was found to be the case whether the surfaces were flat or conical.

Referring more particularly to Professor Benjamin's paper, I may say that I believe he is correct when he says that the load which a ball-bearing can successfully work under is only a small fraction of the strength of the ball. I think, however, that his method of applying the load is open to objection, because of its excessive rigidity. The load should be so applied that nothing but inertia can come into play to prevent adjustment to the slight irregularities which always exist in the size and sphericity of the balls.

When we consider that it takes about 1,000 pounds to change the diameter of a quarter-inch ball by $\frac{1}{10000}$ of an inch, it will be seen that the testing machine might contribute materially to the grinding and locking action.

I made some preliminary experiments on the effect of constraining rings, but did not carry them far enough to get reliable numerical data. I used simply loose rings, external to the balls, with no centering ring. The balls were caused to lift and carry round the rings by turning a slight groove on the inner surface of the ring, into which the balls slipped, at the same time lifting the ring out of contact with the plate below it. The want of a centering ring was a defect, as I found that there was a decided tendency for the rings to run eccentrically, the one above the middle plate going out in one direction, while that below it went out in the opposite direction.

Mr. C. W. Hunt.—My experience has been rather with rollers than with balls, so that I cannot give definite information as to the desirability or strength of this class of bearings. We have

not used balls for bearings, except in a limited way, and then with a slow motion and a very light load per ball. I do not believe that they can be durable in service where the load is enough to affect their sphericity or the integrity of the plane on which they run. The distortion will produce a local action between them which will convert the desired rolling friction into an abrading action. It is also probable that some of the balls will wear faster than others, thus intensifying the strain on the remaining balls.

*Mr. C. H. Benjamin.**—I am glad to know of Professor Gray's experiments, and that they confirm to a large extent my own conclusions. Considering both sets of experiments, it would seem that the following principles have been established regarding ball step-bearings:

1. Under even moderate pressures, steel balls are sufficiently distorted to cause them to seek a spiral path when rolling on flat plates.

2. Coning the plates will only overcome this to a degree, because it cannot be carried far enough without causing the balls to slip and wedge out.

3. The plates deteriorate rapidly when the balls run in one path, on account of the concentration of load.

I believe also that some general conclusions may be drawn which will be of use to designers. These experiments would indicate that the crushing strength of a ball has very little to do with its usefulness in a bearing; that its hardness and resistance to distortion are the true measures of value, that probably the reason why a larger ball will give better service is because its surface is flatter, and that the reason why accurately constructed two-point and three-point bearings do not show better results in service is because even a moderate load changes all the conditions.

* Author's closure, under the Rules.

No. 900.*

A METHOD OF FILING AND INDEXING ENGINEERING LITERATURE, NOTES, DATA, ETC.

BY GEORGE H. MARR, WATERVILLE, ME.
(Junior Member of the Society.)

AT the present time, when, in addition to the regular trade periodicals, there are so many publications devoted to a special subject or manufacture, it is a question with the busy engineer or student how to keep up with the literary side of his profession and devote the necessary time to his regular duties. In many cases a student or young engineer, just starting out on his career, cannot afford to purchase the books nor subscribe for all the trade publications pertaining to his work. Even if he can afford the money, he cannot afford the time to read the numerous articles. The next best thing to knowing a thing is to know where it can be found when wanted. By looking over an article hastily, it is easy to decide if it is worth future reference, and frequently the author's name is sufficient proof that it is worth preserving, or indexing.

The trade catalogues and circulars of to-day are far in advance of those issued ten years ago. Instead of being mere lists and prices of the articles represented, with perhaps a few poor woodcuts and incomplete descriptions, they are oftentimes good specimens of the highest art of printing, engraving, and binding. By the clear and detailed engravings, and lucid description of the article, these catalogues give the best conception of it that can be obtained without seeing the article itself.

In addition to this, many of them contain technical information regarding the processes or methods of manufacture, data, tests, etc., in connection therewith, that cannot be found elsewhere, and are very valuable for reference.

In some cases they contain so much valuable information that they are used as text-books in the classroom. In fact, a person

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

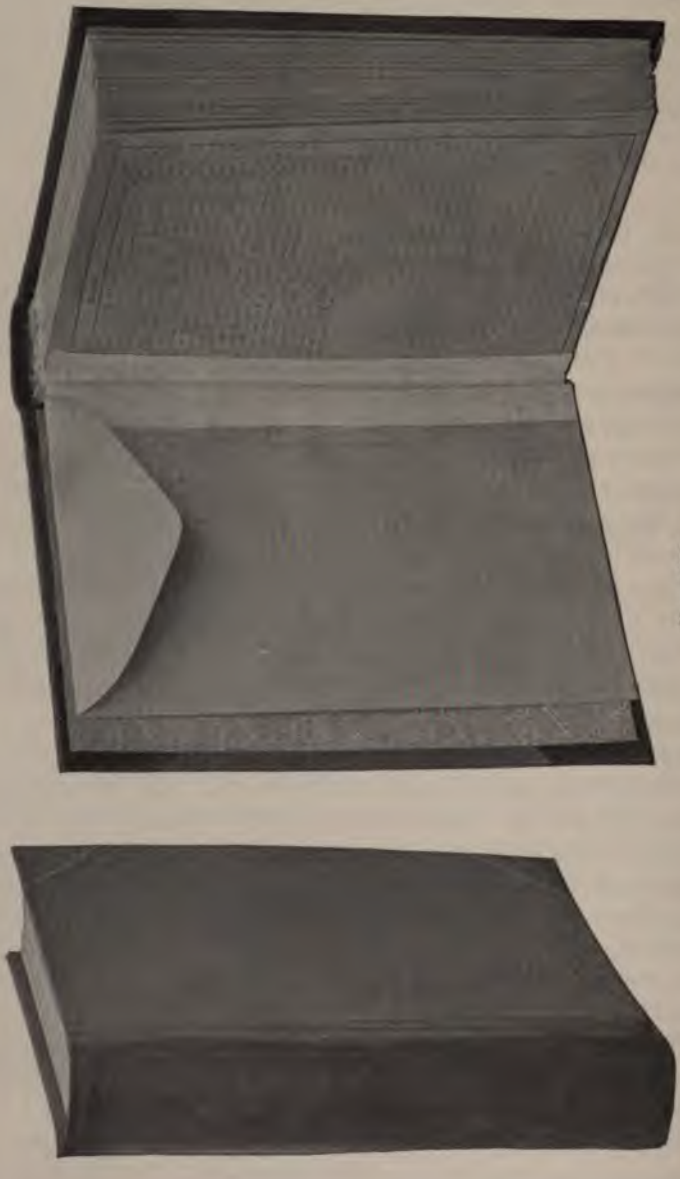


FIG. 300.

can gain considerable insight into the engineering profession from perusing a list of up-to-date catalogues. The engineering handbooks of to-day contain much information which originally appeared in trade catalogues, and the future editions of these handbooks will contain matter which is appearing in current catalogues, and, in many cases, is the result of original research into the subject treated. It is desirable to have such information where it can readily be found.

There are many different methods in use for accomplishing this object, all of them possessing good features, but many of them lacking in some essential qualities.

The writer some time ago adopted a method of filing and indexing such information, which has been improved upon from time to time, and at present seems to possess features not found in any other method which he has seen described.

The notes, clippings, etc., are arranged in Dean's Document File. This file is shown in Fig. 300, and consists of strong Manila envelopes, $6\frac{1}{2}$ inches by 10 inches, open at the end, with flap, and with a binding strip secured to one edge, so that the open end is at the top of the book when bound.

The front side of the envelope is ruled, as shown in Fig. 301. The title of the article is written in the column marked "Subject"; the author's name, in that marked "Authority"; and in the column marked "Issue" is written the abbreviation of the publication from which the clipping is taken, and the date of issue of same. If the information is from some paper or book which it is not desired to mutilate, the name of book and page on which the information may be found is written in the column headed "Issue." In the front of the file there is a leaf giving the names of current publications, with abbreviations to be used when referring to them in the index.

The binding strip consists of a piece of fabric as long as the envelope and about $2\frac{7}{8}$ inches wide, folded to be $1\frac{3}{8}$ inches wide, with a piece of stiff pasteboard about $\frac{3}{4}$ inch wide, pasted into the fold. The two edges of the fabric are pasted to the front and back side of the envelopes, the pasted portion being about $\frac{3}{8}$ inch wide. A row of stitching runs close to the edge of the envelope, and also close to the pasteboard strip, leaving a portion between the rows of stitching about $\frac{1}{4}$ inch wide, which acts as a hinge, and allows the envelope to lie flat while being written upon.

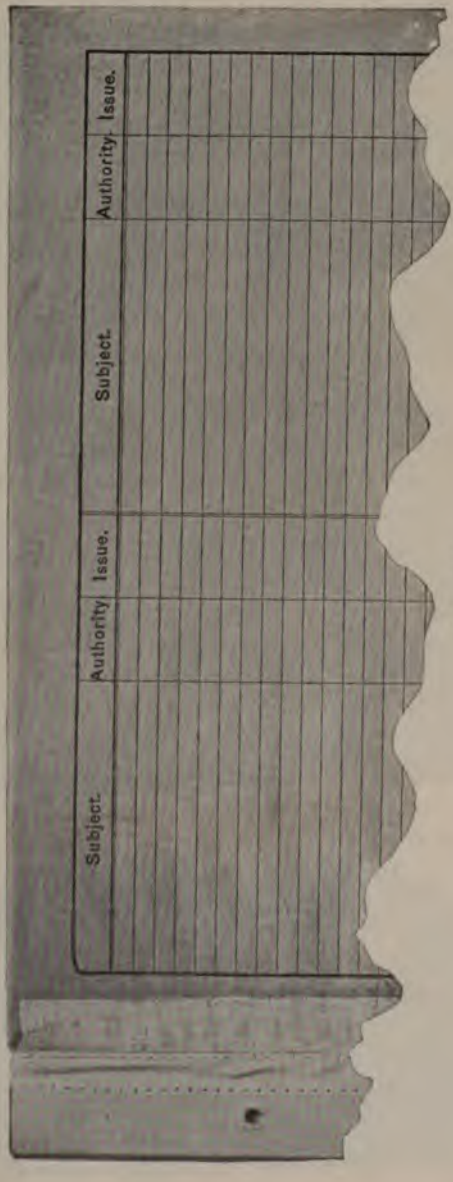


FIG. 301.

The pasteboard strip is of such thickness that it allows the envelope to fill out without "bulging" the volume. It is surprising how much matter one of the envelopes will contain before becoming too bulky. As a general thing, the clippings are so nearly the same size as the envelopes that, when filled, the envelope is of even thickness, instead of being "bulged" out near the bottom, due to the settling of the smaller clippings when the volume is placed on the shelf.

With the size of envelopes adopted, the standard magazine pages can be trimmed so they will go in without folding. Pages of the size of *American Machinist* fold once, while those of the size of *Power*, *Engineering News*, etc., fold twice.

The pasteboard strip is punctured with two holes, which pass over suitable fastenings, secured to the back of a binding similar to a book binding, and having the exact appearance of a bound book when it is on a shelf. The back of the binding has a title, with "Vol. No." and the initial letters of the first and last subjects contained in the volume, similar to the binding of a cyclopedia. The label bearing the initial letters of the subject has an erasable surface, so that, as the file grows and the envelopes are rearranged or carried forward to another volume, the initial letters may be changed to correspond.

The method of securing the envelopes into the binding is such that they can be easily and quickly removed to insert new envelopes or to rearrange as the binding becomes full.

When it is known that there will be a large number of references on a subject, a leaf ruled on both sides, with rulings the same as the envelopes, is inserted in the file, next to the envelope containing clippings on the same subject. In this way the file is given some of the good features of a card index, and the envelopes are preserved for clippings alone.

In the upper right-hand corner are written the first three letters of the subjects which the envelope contains, and in case it is liable to contain a number of clippings on the same subject, the first three letters of the subject are marked in the corner, and the full subject written across the top of the envelope.

Thus, in Fig. 309, the envelope shown is on "Steam Engines," and as it is a subject which is liable to fill one or more envelopes with clippings, it bears in the corner the guide letters, "Eng.," and across the top the subject, "Steam Engines." The

next envelope perhaps would have the same guide letters, "Eng.," but the subject written across the top of the envelope would be "Gas Engines," or perhaps "Rotary Engines." In this way the file can be adapted to a special line of business, and at the same time be a general reference file.

In this system no pasting is required unless a clipping consists of two or more pages, in which case the pages are pasted enough to keep them together. An article printed on both sides of a leaf is available with this method, while but one side could be used if pasted in the ordinary scrapbook.

In case there is an article on each side of a leaf, but on different subjects, and it is desired to preserve them both, the clipping is filed under the subject which is liable to be referred to most frequently, and the other subject is entered on its proper envelope; but in the column headed "Issue" a reference is made to the back of the subject first filed.

If an article is particularly good it is marked "Good" on the envelope after the subject. The approximate number of words in an article may also be noted on the envelope. If it is a cut and description of some device, it is marked "Cut & Des." on the envelope. If it is an advertisement, it is marked "Advt."

By making these short notes in regard to an article when it is filed or indexed it enables one, when looking it up later on, to determine which is the one most likely to furnish him with the desired information.

Manufacturers are fast adopting one or more of the standard sizes for catalogues and circulars, and more will do so when they appreciate the advantage to the purchaser of having his catalogues and circulars of uniform size, or at least of not having more than three or four different sizes. The standard sizes adopted by the principal engineering societies are: $3\frac{1}{2}$ inches by 6 inches, 6 inches by 9 inches, and 9 inches by 12 inches, and it will be noticed that the two sizes of binding cases and envelopes described will take these all right.

The catalogues, pamphlets, etc., are in a set of bindings separate from those used for the filing of notes, clippings, etc., but the bindings are of the same size and construction in each case. The pamphlet bindings have "Pamphlets" and "Vol. No." on the back.

If, for instance, the catalogue to be filed is of the size 6 inches by 9 inches, a binding strip similar to that shown in Fig. 301 is attached, and it is ready to place in the binding.

If the catalogue contains information that is deemed worthy of a place in the clipping file, the desired pages are taken out of the catalogue and placed in the envelope of the reference file under its proper subject.

If it is desired to refer to the articles treated in the catalogue, the manufacturer's name is placed in the column of "Authority," and the catalogue is referred to in the column "Issue" as "Pamphlet No. —," "Vol. No. —."

If the catalogue is 6 inches by 9 inches, but bound along the 6-inch edge instead of the 9-inch edge, or if it is enough smaller than 6 by 9 inches so that its small size would make it inadvisable to bind with the binding strip, it is placed in an envelope similar to those used for the reference file, and then bound in the pamphlet file. If the catalogue or pamphlet contains more than 50 pages, instead of placing a binding strip along the back the pamphlet itself is punched near its bound edge with holes matching those in the binding strip, and it is then placed in the binding. In many cases, if the pamphlet is a little larger than a standard size, it can be easily trimmed to the standard without destroying any of the printed matter.

What has been said in regard to the improvement in catalogues during the past ten years will apply also to advertisements, some of which, in addition to one or more half-tone cuts showing the machine or object advertised, also contain considerable information in regard to it. Oftentimes the advertisement of a new article or process is the first information given to the public in regard to it. The writer files away such advertisements the same as clippings, and finds frequent occasion to refer to them.

The specimen filing envelope shown in Fig. 300 contains cuts and advertisements of leading makes of steam engine, each showing the type and general appearance of the engine manufactured, and at the same time gives the address of the builders.

For filing drawings or designs of special interest, which it is desirable to fold as little as possible, a file containing envelopes 9½ inches by 13½ inches is used, the rulings being the same as on the other envelope. This size also contains pamphlets of the standard size, 9 inches by 12 inches. It will also take the ordinary size of business letter sheets and typewriter paper without folding.

Persons who have used notebooks of the usual kind find

after a few years that they have a fine collection of notes, but usually no good index to them, so that a desired note or calculation cannot be found without looking through the whole collection, which often requires considerable time. In order to overcome this difficulty and at the same time get as much service as possible from the filing system described, the writer adopted the "Morehouse" notebook, which has detachable leaves and indexes, so that the contents are always indexed, and at the same time, if desired, any leaf may be removed, as in the case of obsolete matter, for instance, and the later data on the subject substituted.

Section-ruled leaves make it convenient for sketching or tabulating data. The detachable leaves make it possible to do all sketching or tabulating on a single leaf lying flat on the table, which, when finished, is placed in the notebook under the proper index. As the notebook becomes filled, the matter which is the least liable to be used in every-day work is removed and placed in the envelopes of the file containing matter on similar subjects. In this way the notebook is always up to date, and at the same time all previous notes and data are filed away and indexed, so that they can be referred to as readily as a word in a dictionary. The writer finds this method of keeping notes, etc., far ahead of anything he has yet seen for the purpose.

An article is first indexed or filed under its most suggestive title, and then, if necessary, cross references are made, so that if the general subject of the article is known it can be found with little trouble.

By using envelopes with different rulings from that described, the matter may be indexed in more minute detail if desired.

While it is considerable work to file away accumulated matter when first starting the system, it is very little work to keep it up to date.

The titles of papers read before the various engineering and siecntific societies are now published in many of the current periodicals, and some of them also publish an "Index of Current Literature," giving the titles of articles on various topics appearing in the different periodicals, so that a person by using this filing system can keep a record of all important articles on such subjects as he is most interested in, and yet be a subscriber to only a few of the periodicals.

More than ten years' use of this system has demonstrated its

usefulness to the student or engineer, and while it may not possess all of the desirable features of such a system, it contains enough of the more important ones to make it of great value to its possessor, and its value increases daily.

DISCUSSION.

Mr. William Wallace Christie.—I have followed the classification suggested by Mr. W. L. Chase in Paper 809, Vol. 14, in filing catalogues and circulars. I use pasteboard boxes the size of ordinary letter files.

The card index to the subjects is complete with about 400 cards, so that it is not at all bulky.

Of course, it has been necessary to extend the items in the list given by Mr. Chase, which I have done in the subdivision according to my own fancy.

For engineering notes I use $5\frac{3}{4}$ × 9 inch sheets of paper, punched in the back, numbered as in Fig. 302, 24 being the

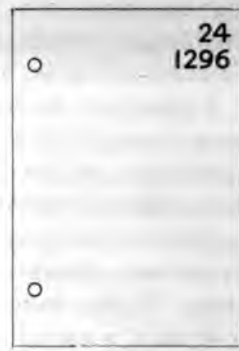


FIG. 292.

classification, 1296 being the current number of the sheet then used.

When the sheets are placed in the covers provided for them, they are indexed in a book provided for the purpose.

One can readily see that if classification work is done carefully, the number—24, for example—only appears once [after a name], all other sheets on the same subject being under the same number 24. For example, Steam Boilers, vertical—30; 1292, 1421, 1825, 1926.

While this method of keeping notes may not be all that any one else may wish for, it has been a very satisfactory way for the writer.

Mr. Howard Wells Smith.—This is a subject for which it is pretty hard to give any fixed rules. For my part, I have found that the envelope system does not work very well. For instance, if you devote one envelope to a certain subject, that subject naturally increases from time to time—that is, its literature does—and before long the envelope is full and all the titles have been used up; then, especially if one is interested in any particular branch or branches of the subject to which that envelope is devoted, he has to divide up the contents, and trouble comes with taking everything out of the envelope, or the two or three envelopes, if possibly more than one have been used, doing the separating and rewriting of all the titles. So that I believe that each piece of information should be kept distinct. There is no trouble in putting these pieces into a box or boxes and keeping them like cards, so that each one can be numbered and have its own subject or index in any system; but the principal thing is to keep each distinct, so that the bunch can be divided into classes at any time, without troubling to rewrite the titles.

Prof. L. P. Breckenridge.—This is, I believe, a matter of opinion and necessity. I think all schemes are poor. I think those of us who have been through all the poor ones and never found a good one, may perhaps be of the opinion that the library people are right, and that a decimal classification is, after all, as good as anything. I believe that the final decision will be something in the nature of a decimal classification, such as has been used in our large libraries. It has seemed to me that possibly some good would come of it if a committee were appointed to discuss this matter before there are so many plans of this description suggested. It is about as useless to attempt to persuade any one that your scheme is best as anything I can imagine. It is like trying to demonstrate that your child is the brightest one in the world. There is one factor in connection with this method of indexing in which I have been somewhat interested, and which I will suggest; that is, the possible chance for technical schools to take up this matter. At the University of Illinois, for the last two or three years we have been undertaking it a little, and have recently assigned some senior students to keep up card indexes of certain journals; these card indexes have been turned

into the department, copied and then returned to the students, while the department copies are put on file for general reference. The cards thus prepared have recently been copied by the Western Society of Engineers, and they now have on file in Chicago at their rooms (1734 Monadnock Building) something like three or four thousand of these cards. It seems to me that there would be a chance for the technical schools to do something along this line which might be helpful to engineers, if any coöperation could be secured among them. That would necessitate, of course, uniformity as regards the methods of classification adopted. We have attempted to get up an extension of the subjects as used in Dewey's decimal classification that has answered our purpose very well, thinking it best to stick to an established plan like this, rather than to try and get up a new plan that has not been generally adopted.

Mr. Smith.—I would say that the Dewey system just mentioned has worked very well with me.

*Mr. George H. Marr.**—The discussion of this paper brings out the fact that no system seems completely adapted to every user's needs, but, as suggested in the above paper, each user, or class of users, must modify a system to meet his or their individual requirements.

In regard to Mr. Christie's discussion of the subject, it seems to me that the system described in the above paper possesses all of the good points of his method and some additional ones. The sheets of paper he uses ($5\frac{3}{4} \times 9$ inches) are almost the exact size of the envelopes used in the writer's method, and could be placed in the envelopes the same as the detachable notebook leaves mentioned in the writer's paper. The envelope also contains clippings on the same subject, the titles being entered on the rulings on the outside of the envelopes, as well as reference to data on the same subject contained in books or other publications, so that all the data and references on a subject are collected together, either inside or on the outside of the envelope or envelopes devoted to the subject, and the index letters in the upper right-hand corner of the envelope make it easily found in the file, and do away with the necessity for writing the index in a separate book or card index.

In Mr. Howard W. Smith's criticism of the paper he brings

* Author's closure, under the Rules.

up the objection that after an envelope or envelopes have become filled, it is necessary to rearrange the matter in them and rewrite the titles, but the writer, during more than ten years' use of the system, has never seen the necessity of disturbing the matter in any of the envelopes after it had once been placed and indexed.

To show the elasticity of the system, I will state that, being interested in microscopical research, and wishing to file my notes and data on that subject separate from all other data, I placed in my file under the index letters "Mic" a number of envelopes bearing across the top the title "Microscopy," followed by the alphabetical letters A, B, etc., one to each envelope, so that the matter on this subject was quite thoroughly subdivided, and at the same time was included in the regular file and as easily referred to as any other subject. The same could be done with any or as many subjects as were specially interesting to the user or owner of the file.

The writer is familiar with the Dewey Decimal Classification, as applied by Professor Breckenridge at the University of Illinois, and, while admitting the excellence of the system, can see no reason why the same idea cannot be carried out in connection with the system under discussion.

It would seem that the latter system had some points of advantage over that described by Professor Breckenridge. For instance, take the subject of Governors: under the Dewey Classification it would be necessary to look under the subject of Steam Engines, Water Engines or Motors, Pumps, Air or Gas Engines, Electrical Machinery, etc., in order to find the governors used for these different purposes, while in the system under discussion, under the index "Gov," and in the envelopes marked "Governors," would be found everything pertaining to governors for any use whatever, and the same will apply to many other subjects.

No 901.*

PROTECTION OF FERRIC STRUCTURES.†

BY M. P. WOOD, NEW YORK, N. Y.

(Member of the Society.)

1. The last thirty years have worked a revolution in the construction, armament, and equipment of the navies of the world by the substitution of iron and steel in the place of wood. This change is of equal moment in the design, materials, and construction of the merchant marine, also of the thousands of railway bridges, viaducts, public buildings, and other structures now so essential to the necessities of modern life. This change from wooden construction to iron and steel has centred around it the best minds and efforts of modern times, and may be taken to represent the concrete civilization of a thousand years. The impulse is onward and upward to a still higher plane, and with our rapidly decreasing forests and timber supplies, and the rapidly narrowing margin in the difference of cost between a ferric structure and one built of wood, it may not require another equal period of time to see nearly all of our domestic structures built of metal instead of wood, with a greater security from risk of fire to add to the many other advantages in the change.

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* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† For further discussions on this topic, consult *Transactions* as follows:

No. 598, vol. xv., p. 998, "Rustless Coatings for Iron and Steel." M. P. Wood.
No. 626, vol. xvi., p. 350, "Rustless Coatings for Iron and Steel." M. P. Wood.
No. 637, vol. xvi., p. 663, "Rustless Coatings for Iron and Steel." M. P. Wood.
No. 713, vol. xviii., p. 251, "Rustless Coatings for Iron and Steel." M. P. Wood.
No. 600, vol. xv., p. 1087, "Corrosion of Steam Drums." Jas. McBride.
No. 595, vol. xv., p. 961, "Corrosion of Cast Steel Propeller Blade." F. B. King.
No. 436, vol. xii., p. 518, "Topical Discussion."
No. 291, vol. ix., p. 429, "Corrosion of Condenser Tubes."
No. 302, vol. ix., p. 536, "Corrosion of Fire-boxes."
No. 108, vol. iv., p. 221, "Corrosion of Column Pipes."
No. 180, vol. vi., p. 628, "Oxidation of Metals." W. H. Weightman.
No. 123, vol. iv., p. 351, "Bower-Barff Rustless Iron Process." G. W. Maynard.
No. 72, vol. iii., p. 248, "Note on Action of a Sample of Mineral Wool." F. R. Hutton.

2. But our knowledge or rather our methods for the preservation of ferric bodies from corrosion have not kept pace with our knowledge and methods of construction, and the consequence is that in thousands of ferric constructions, from the least to the greatest, after a brief existence, we find corrosion has gained a footing, and the structure instead of having an assured life of centuries is measured by that of a few decades. It may be stated almost without question that not 30 per cent. of the ferric structures of any kind or character in the United States have ever received a protective coating which is worthy of its name; per contra, that the very first steps taken with a view to prevent corrosion, whether at the shop during manufacture or at the site while being erected and covering in, are radically wrong, and have been so demonstrated by actual experience for thirty years in thousands of instances and locations, and yet not a few of our eminent construction and railway engineers fail to draw either lesson or deduction from the past failures of their predecessors' work, and blindly repeat them. At the risk of repeating a thrice-told tale, I propose to review some of the notable instances of failure to protect our ferric structures from corrosion, as well as to note some instances of success, trusting that the review may cause a more rational treatment of a matter on which depends the security of thousands of lives and thousands of millions of dollars' worth of property.

Iron Oxide Pigments.

3. Probably at this date iron oxide pigments, either in their natural condition, as ground red or brown hematite iron ores, or the same as a base to which a score of other substances are added by the paint compounding manufacturers, have been more generally used than any other pigments, natural or compound, for the protection from corrosion of ferric structures, and to the extended and careless use of them under their many trade names may be attributed the corrosion in ferric structures that greets the eye, go where one may.

4. The color of these paints varies from a dark, dirty, purple brown to a bright dark red—the Indian red of commerce. Their color is due to the processes of roasting, grinding, and subsequent doctoring of the product to get a desired color tone. A few degrees more or less of heat, or a few seconds more or less

exposure to the same, evolve a great diversity in the color even if the composition of the pigment remains unchanged.

5. Analyses of some of these hematite ores are given which will convey in some measure the heterogeneous character of the substances in the native ores, from which to select one which will embrace the claim to "never fade," "never wear out," "always protect any wooden or ferric body from fire, rot, corrosion, or wet, regardless of situation or condition."

ANALYSES OF BROWN HEMATITE IRON ORE, HYDRATED.

Twenty-four different ores by different analysts.

Ferric oxide	90.05 to 32.74	Averages,	59.54	Eleven samples averaged metallic iron 52.55 per cent. Thirteen samples averaged metallic iron 33 81 per cent.
Ferrous oxide	traces " 10.54	"	1.23	
Manganese oxide	3.06 " 0.05	"	0.87	
Alumina oxide	27.95 " 0.05	"	4.48	
Lime oxide	0.06 " 25.70	"	4.20	
Magnesia	0.17 " 10.21	"	1.80	
Silica	63.52 " 0.79	"	13.90	
Carbonic acid	0.16 " 18.45	"	3.83	
Phosphoric acid	0.06 " 3.17	"	0.63	
Sulphuric acid	traces " 0.28	"	0.03	
Iron pyrites	traces " 0.30	"	0.03	
Water hygroscopic and combined	18.60 " 6.60	"	10.25	

Percentages of metallic iron, 63.04 to 24.09. Averages, 42.45.

ANALYSES OF RED HEMATITE IRON ORE, ANHYDROUS.

Twenty different ores by different analysts.

Ferric oxide	98.71 to 66.55	Averages,	89.13
Ferrous oxide	traces " 1.13	"	0.16
Manganese oxide	9.13 " 0.10	"	0.31
Alumina oxide	2.79 " 0.06	"	0.82
Lime oxide	9.40 " 0.07	"	1.97
Magnesia oxide	1.39 " 0.06	"	0.42
Silica	8.90 " 1.00	"	5.77
Carbonic acid	5.73 " 0.78	"	1.35
Phosphoric acid	1.02 " traces	"	traces
Sulphuric acid and iron pyrites	1.31 "		"
Water hygroscopic and combined	2.12 "		"

Percentages of metallic iron, 69.10 to 47.47. Averages, 62.37.

Specific gravities, 3.80 to 5.38.

6. With this wide variation in the composition of the above iron ores, selected not only on account of the metallic iron in them, but also for the small amount of lime, magnesia, carbonic, phosphoric, sulphuric acids, and pyrites, what may not be inferred as to the composition of the other iron oxide mines whose product, used for pigments instead of smelting purposes, have

20 to 40 per cent. of ferric and ferrous oxide, with greater amounts of silica, lime, magnesia, sulphuric and other acids, pyrites, and water? As a rule the lower the amount of metallic iron in the ore the greater is the amount of the latter substances, which are not only detrimental for smelting purposes, but are also much less acceptable for a protective covering for either wood or iron, and whose decorative qualities lie principally in the direction that they do not look as bad as something else. Now, the process of roasting these hematite ores for pigments is with a view to the color, and to expel the water, sulphuric and other acids in them. But this roasting does not expel all the sulphur and other acid elements, only about one-half of whatever amount of these acids may be in the ore under treatment, even if the heat be long continued, which would ruin the color. The balance of the SO_3 and CO_2 and other acids is only excited by the heat to a greater activity to restore a disturbed condition of their composition; besides, the lime and magnesia are rendered caustic, and, when mixed with the oil carrying more or less uncombined water in it, slack the same as lime slacks in a mortar bed and set up a chemical action in the freshly applied paint which, if it does not delay the drying of the coating, must have some effect upon the same, which from experience we know to be detrimental. To neutralize the sulphur element natural to the ore or developed in roasting, it is the common practice to add carbonate of lime (common chalk) to the amount of 5 to 10 per cent. by weight of the iron oxide, which, combining with the sulphuric acid, changes to a synthetically formed sulphate of lime (gypsum) which, however inert as a pigment and admirable as a stuffing, is not as desirable in this form as the natural gypsum would be. This change from a carbonate to a sulphate is wholly a chemical one and takes place only when in the presence of and in contact with the oil, and is exerted at the critical moment of the first drying of the coating; and as it is not an instantaneous combination, the chemical action continues even after the paint has set and necessarily must affect the whole character of the coating, particularly the menstruum, the decomposition of which may be said to have commenced before it was fairly dry or even put on. This chemical change is accompanied by an increase in volume of the carbonate, acting as a mechanical force upon the coating, as will be hereafter noted.

7. The value of iron oxide paint as a protective coating for

any ferric structure has been forcibly presented in a paper, No. 752, vol. xxxiii., *Transactions American Society of Civil Engineers*, June, 1895: "Painting of Iron Structures Exposed to Weather." This paper is a report of a special examination of the condition of the protective coatings on a large number of important railway bridges, viaducts, etc., many of which had been constructed and delivered as finished structures; the preservative methods employed being (as stated), in most cases, the selection of the bridge-construction firm.

8. The evidences of corrosion on these structures had become so serious as to attract attention even in the few years that they had been erected, and to ascertain their actual condition one of the bridge staff of engineers was detailed. He reports visiting twelve locations and fifty-three structures of greater or less importance, thirteen of which were painted with an iron oxide paint trade-marked "Cleveland Iron-Clad Paint, Brown Purple No. 3," which, from the analysis given on page 521 (his report), is a hematite ore from the Lake Superior region, unroasted and not distinguishable from hundreds of other red or brown hematite iron ores, except as being very rich in sesquioxide of iron, viz., 93.04 per cent., equal to 65 per cent. metallic iron combined with 28 per cent. oxygen. Every pound of this pigment carries three times as much oxygen as a pound of red lead pigment, and a gallon of red lead paint would have to contain $23\frac{1}{3}$ pounds of red lead pigment to equal the oxygen element in $7\frac{1}{2}$ pounds of this iron oxide paint, and yet the advocates of the latter paint prate loudly of the awful combustion of the oil as a consequence of the use of red lead, presumably to cover the deficiencies of their own compositions as protective coatings. (See forward, Smith's paint test.) No analysis of the engineer's own firm's iron oxide paint is given, nor does he mention (except in a single instance) the structures which he examined as having received his firm's special paint, but mentions that a patent paint was used on some of the structures which consisted of about 33 per cent. of iron oxide and 60 per cent. of silica. What the remaining 7 per cent. was composed of is not stated, but presumably it was a chalk stuffing.

9. Eleven of the 53 structures mentioned were coated with oil at the shop, and received two coats of iron oxide paint when erected. Included in this number are the Blair Crossing Bridge (especially under the examining engineer's own care during

erecting, and painted with his firm's own iron oxide paint), the Rulo and Leavenworth Bridges, and St. Louis Elevated Railway structures. The condition of these structures as described ought to set at rest forever the utter worthlessness of an oil coating as the foundation coat for any paint on an iron structure, even if the other seven oil coating examples did not bear testimony to the same effect—*but they did.* Twenty-two bridges reported upon were painted with iron oxide at the shop and received two coats of the same paint after erection, and obviously are in no measure an improvement upon the eleven above noted, and all are a sorry record of the means employed in past-day engineering to protect important ferric structures from corrosion. Six of the bridges had received red lead coatings; five, red lead as first coat and iron oxide external coatings. The condition of these structures, as well as nine others painted with unknown or uncertain pigments, were evidently no worse than those of the iron oxide class, and all showed the general failure of contracting and in-charge engineers' methods to properly protect their work from elemental destruction.

10. The physical condition of these 53 structures in no measure sustains the engineer in his final deductions in favor of iron oxide paints as against red lead or other paints, or that an oil coating was the best foundation for the other coatings, or that raw linseed oil is superior to properly boiled linseed oil as a menstruum—conclusions that the members of the A. S. C. E., who took part in the discussion of the paper, both orally and by correspondence, were overwhelmingly against. The condition of these bridges is probably a fair representation of a majority of the railway bridges in the United States, the greater number of which have received the same or a similar treatment against corrosion which has proved to be inadequate for that purpose in the instances reported, and similar conditions would be found to be the case in hundreds of other bridges erected and painted prior to 1895, if examined and reported upon in detail.

Boiled Oil versus Pigment Coatings.

11. Many eminent engineers have abandoned the use of iron oxide and other uncertain patent paint compounds, but still adhere to the use of oil for the first coating. The writer believes this method will bear fruit at no distant day in as calamitous a

corrosive result as has attended the use of iron oxide, particularly in the case of all suspension bridge cables, anchorage bars, lattice trusses, and other enclosed places where inspection or replacement is practically impossible. Certainly, a pigment coating can be applied anywhere and as easily as an oil coating, will dry as quickly and as hard, and at any stage of drying will resist mechanical injury due to handling, transportation, and erection better than the oil coating, and if storms of any character reach the coating, as they certainly will, they will not so injuriously affect it, either in a minor or major degree, as they do an oil coating. Finally, if the oil coating is so supremely good for the foundation coat, why not extend the goodness and make *all* the coatings of oil alone, and save the cost of the pigments in the subsequent coats, and retire the whole corps of paint compounders and salesmen to the shades where rest the remains of the lamented iron oxides? The protective qualities of an oil coating compared with a paint is forcibly shown by Dr. Dudley's experiments for the Pennsylvania Railroad, viz.: Several samples of a paint were made from raw linseed oil and a small quantity of japan, the same vehicle and pigment being used for all the samples with varying amounts of pigments, all the proportions being by weight. Two coats of these paints were spread upon glass, and each allowed to harden for two weeks. The samples were then placed side by side and a small portion of the surface of each was covered with a globule of water which was covered to prevent evaporation, and then allowed to stand for twelve to fourteen hours.

Sample No. 1 was the linseed oil and japan alone.
" 2 was the same liquid 90 parts, pigment 10 parts.
" 3 " " 80 " " 20 "
" 4 " " 70 " " 30 "
" 5 " " 60 " " 40 "
" 6 " " 50 " " 50 "
" 7 " " 40 " " 60 "

At the end of the period the condition of the samples was as follows:

No. 1 had cleaved off from the glass and had shrivelled wherever the water had touched it. On allowing the water to evaporate the coating dried down again, but not uniformly. It was weakened in texture and had apparently lost its bond to the glass.

No. 2 showed the same characteristics.
No. 3 showed the same but in a less degree.
No. 4 did not cleave from the glass, but showed where the water had stood.
No. 5 showed a spot in the same way, but in a less degree than No. 4.
Nos. 6 and 7 showed but very little action beyond a slight discoloration.

What more evidence need be presented to show that the use of oil alone for the foundation coat is radically wrong, and the sooner abandoned the more to the credit of modern day engineering practice? No theory that the oil alone will soak into or beneath the loose, or partially loose, scales and rust on the body coated is tenable in the face of the fact that these scales and rust must be removed in order to secure a favorable result with any coating. There is absolutely no excuse for allowing them to be coated over, or incorporated into any coating. Doctor Dudley's results are in direct line with and corroborate the tests of Professor Smith, Toltz, and others hereinafter given.

12. Rust proceeds solely from the action of an acidulated moisture upon a bright or clean iron surface, and is probably only a point at its inaugural. The affinity of the iron for the oxygen in the acidulated moisture of the air or water in the oil, or from other sources, is greater than its bond with the hydrogen as water (H_2O); the decomposition ensuing releases the hydrogen, which is 16 times the volume of oxygen, united with the iron to form hydrated Fe_2O_3, or red rust. The hydrogen, from its light specific gravity, in its effort to escape into the air pushes up the overlying paint coating, increases the area of the affected part, cracks the coating in its exit, moisture enters again, and corrosion is master of that location. The rust which has thus been formed is hygroscopic and carries 24 per cent. of moisture as it forms. This moisture *never dries out* under any atmospheric heat conditions, but is ever ready for a chemical decomposition, the hydrated red rust formed, being over two times the volume of the iron from which it is formed, adds its efforts to the free hydrogen to push up the coating and form a blister and crack in the coating. How energetic this mechanical action due to corrosion is, may be observed by noting the ordinary cast-iron hand railings for fences and outside steps of New York City and other city houses, which in hundreds of instances are split for more or less of their length. Cast-iron water or gas pipes, with bell and spigot joints, are frequently made with rust joints. They

almost invariably burst the bells by the swelling of the iron cement used to make the joint.

13. Late advices as to the condition of the great cantilever bridge over the Firth of Forth,* Scotland (finished less than 10 years ago), show that corrosion is well and widely established over the entire structure, notwithstanding a corps of painters are continuously employed upon it, and the structure is practically repainted every three years and in many places yearly. Upon the lower parts, where the iron work rests upon the masonry, and upward where the spume and salt spray from the sea reaches the work, corrosion has attacked the rivet heads and laps of the angles, channel bars and plates, and cannot be controlled by the scraper and paint brush. This structure received two coats of boiled oil at the shop before erection, and then two coats of iron oxide paint, each of which required 90 tons of paint. It is the opinion of the writer that before the bridge has had thirty years of existence it will have to receive the drastic action of the sand blast for all parts which can be reached by that process, and that even that will not wholly remedy the evil; that the lower sections for 20 or more feet in height from the masonry piers will be so corroded they will have to be cut out and renewed, if they can be; that thousands of the rivets, many of them $1\frac{1}{4}$ inches to $1\frac{1}{2}$ inches diameter by 9 inches in metal, will be so corroded under their heads as to have lost their set. In fact, the stability of the bridge in the future will rest quite as much upon its mass as upon the mutual strength of its connecting members. Some one was knighted for the ability shown in the construction of this bridge; it may be that somebody else will get *two* buttons on his bonnet for being able to take care of it.

New York Elevated Railway Viaduct.

14. The viaduct over the Harlem Station of the New York Elevated Railway at 155th Street was oil-coated, and received oxide of iron paint coatings at the time of its erection, and within five years of its completion had developed corrosion to such an extent that in 1897 the sand blast was used to clean it preparatory for another effort for its preservation. This sand blast process cost about $10,000, or over fifteen cents per square

* *Trans. A. S. M. E.*, December, 1894, vol. xvi., paper No. 626, pp. 407–408.

foot to apply, or about seven times more than a properly selected method of procedure and paint would have cost in the first place, and then only the lower and accessible sides or parts in sight received treatment, while the top side, out of sight and, from its inaccessiblity for inspection, more important to protect, got no sand blast and corrosion was left free to run riot. About 50,000 square feet of surface was cleaned by the sand blast to the bright iron, removing about 12 tons of old paint, scales of rust, and cinders, showing a number of distinct layers of highly corroded matter. Full particulars of the air blast mechanism, illustrated, are given in the *Engineering News*, September 23, 1897; also, *Engineering Record*, September 25, 1897.

15. Seventeen panels of lattice truss, floor beam and buckle plates, supporting the paved carriage roadway and footpaths overhead, about 2,825 square feet of surface each, and numbered consecutively 1 to 17, were then painted with the same number of selected protective coatings furnished by a like number of paint firms in competition with each other. The several coatings were applied in strict conformity to the directions received with each brand of paint, the application being to the bright iron as left by the action of the sand blast, and within 3 to 4 hours from the time the sand blast ceased action, the paint being spread by the painters employed by the Board of Public Works of New York City. Every possible condition was brought into bearing to make the test one of a practical and commercial nature as well as of scientific value, absolutely without prejudice or favor in any respect. From the prominence of the structure in an engineering view and its situation, exposed to storms, sea air, fog, cinders, steam, and gases from scores of locomotives in constant service beneath it, nearly all of the metal being within a few feet of the tops of engine stacks and receiving the products of combustion under blast action and in an approximately closed space, the future result was anxiously looked for as an important demonstration of the practical value of the several best protective coatings in the market.

After an exposure of about nine months, and while a few of the coatings, viewed from the station platform, showed evidences of failure, a thorough examination of the condition of each panel was made by a prominent engineer of New York City (see *Engineering News*, May 24, 1898). This report is of ex-

treme interest and value to engineers, and is summarized, viz., 100 rating as a perfect condition of the coating.

Number of Panel.	Number of Coats of Paint.	Kind or Name of Paint.	Rate of Drying.	Freedom from Rust, per Cent.	Reference Marks as to Condition.
1	3	Lead, graphite and lucol oil.....	Medium	97	*a*
2	2	Amorphous graphite, Detroit Co.—L.S.G.	Slow	80	*b*
3	2	Red lead, antoxide, F. and D.....	Fast	25	*c*
4	2	Graphite (kind not stated)	Slow	75	*d*
5	3	Nobrac (trade-mark).....	Medium	99	*e*
6	2	Carbon Black (F. W. Devoe & Co.).....	Slow	85	*d*
7	2	Durable Metal Coating (E. Smith's varnish)	Slow	75	*d*
8	2	Black Manganese (iron paint).....	Fast	30	*f*
9	2	Carbonizing Coating (trade-mark)	Slow	80	*a*
10	4	Mineral Rubber (no particulars).....	Fast	78	*g*
11	2	Black (composition not given).....	Medium	58	*h*
12	2	Carbon (no particulars).....	Medium	92	*a*
13	2	Graphite (Standard Oil Co.). Kind not stated.....	Medium	67	*a*
14	2	Graphite (Dixon Co.). Kind not stated..	Slow	70	*d*
15	2	Asphaltum (California Co. brand).....	Very slow	65	*j*
16	2	Ruberine (trade-mark). Composition unknown	Medium	58	*k*
17	2	Black Diamond (trade-mark).....	Medium	70	*l*

a Very little rust. Paint crumbles in places as though rotten. Easily removed.

b Fair condition, but discolored; rust coming through.

c Very badly rusted.

d Rusty, but not deep.

e Slight rust on top flange of one girder; rest of girder clean.

f Rust very deep; buckle plates bad.

g Area of rust spots small; rust not very deep.

h Rust very bad and deep.

j Deeply rusted; buckle plates still good.

k Rust very deep and angry; buckle plates mildewed.

l Small pimples of rust, as though formed under the paint.

16. Panel No. 1 was an outside one, and the first to be sand-blasted and painted with three coats of paint in the clear hot days of summer, a material advantage in its favor. The sand blast was then shifted to the southern end of the viaduct; and panel No. 17, also an outside one, was the next one cleaned and painted in hot clear weather, and so on consecutively, in the reverse order of the panel numbers, back to No. 1, panels Nos. 7 to 2 having been done late in the fall under unfavorable conditions as to the spreading and drying of the paint in addi-

tion to the other objectionable conditions. About 80 square feet of panel surface was cleaned per hour, or 600 square feet per working day; each panel requiring from five to six days to clean and paint it.

17. It will be noticed that panels No. 1 and No. 5, rating in the best condition, each received three coats of paint, while all of the others (except panel No. 10) received only two coats; the high ratings of these panels may in a measure be attributed to this extra coat. But panel No. 1, also Nos. 9, 12, and 13, while rating high as to the non-appearance of rust, yet the actual condition of the coatings in being rotten, easily removed, crumbling under touch of the fingers, indicated a poorer condition to resist corrosion on a longer exposure than panels Nos. 2, 4, 5, 6, 7, and 14, which may be considered as being in an approximately fair condition, and far better coatings than those rating higher, but in a rotten condition.

18. Panels No. 1 (97 per cent.) and No. 3 (25 per cent.), in which red lead formed one of the pigments in the paints, were no doubt destroyed by the action of hydric sulphide in the combustion gases from the locomotives, changing the lead oxide to a sulphide, with an increase of volume of about 33 per cent. This action will be given in more detail hereafter. The difference in the ratings was due to the greater amount of lead in No. 3 than in No. 1, and the higher rating of No. 1 being in no measure due to the menstruum, but solely to the smaller amount of lead. It is quite probable that the coatings on panels Nos. 9, 12, and 13, whatever the pigments might have been, were mixed with oil-carrying lead driers in excess, which would be attacked by the hydric sulphide the same as if the lead oxide was in the pigment. This change in an oxide or carbonate of lead is effected by an inexorable chemical law whenever they are exposed to hydric sulphide, and should have been foreseen by the chemists of the paint firms interested.

19. Panel No. 10, with four coats of a quick-drying paint, was evidently an asphaltum paint, with either benzine or bisulphide of carbon as an extra drier. Had only two coats of this paint been applied, its condition would have rated as low as panel No. 8, and, taken in connection with the other paints that had asphaltum as the base pigment, showed the same unreliable results which have attended the use of asphaltum compounds wherever they have been exposed to anything beyond the most

ordinary conditions of service upon minor structures. See Toltz's and Smith's tests farther on.

20. Panels Nos. 11, 15, 16, and 17, whatever their ratings from their outside surfaces, showed a worse condition of the metal beneath the coatings than any of the others. A greater or less amount of asphaltum in their pigments, compounded with other equally unreliable substances to form the basis of a patent or trade-mark, is probably the cause of their low merit as given in this case. There is but little doubt that the majority of the persons interested in the several paints applied to this structure gladly welcomed the closing act in this test, when, shortly after the issue of the engineer's report, the Board of Public Works gave the order to repaint the whole structure; which was done with (to the writer) some unknown paint, applied over the several test coatings in place without removing, except in the most perfunctory manner, the old coatings with their fast forming burdens of rust, and the competitive test came to an end. The result could have been foreseen from the first, before a single truss or pound of material had been placed in position or was even out of the construction shops, had not commercial greed, official indifference or ignorance, either one or all, ruled the matter.

21. The destruction of the tubular railway bridge over the St. Lawrence River at Montreal, Canada, had not become a fact so musty with age as to have escaped attention concerning the dangerous effect of hot combustion gases upon any paint coating in a confined space. Corrosion history blindly repeated itself when the viaduct material was first painted by the contractors, then repeated the "Comedy of Errors" when it was erected, and again when it was sand-blasted for its final fiasco. The plain facts of the painting after the sand blast action are, that the coatings were destined for an early destruction from the first, by reason that the first coat was applied in an atmosphere saturated with the hot vapors of combustion and steam, which were so corrosive that the freshly cleaned surface of the metal showed a blush of rust within an hour after cleaning, and if left for three hours the rust could be wiped off by the hand. The paints were spread in this atmosphere, and before they could in any measure dry, so as to be in any degree resisting, they were thoroughly impregnated by the hot gases and steam, which left their condensed strength upon the surfaces of the green

paints. The second and subsequent coats were not only applied under the same atmospheric conditions as to the hot vapors and cinders, but had the condensed products of combustion sandwiched between them. Probably a baked japan or Bower-Barff coating are the only ones which would have successfully met the situation, which is an exceptional one. Such coatings would not have cost one-half as much as the sand blast and the several coatings applied in the first and subsequent stages, and would have been thoroughly protective and avoided nearly all the future expense in the care of the structure so far as the painted surfaces are concerned. It is to be hoped that the many engineering structures now in progress in and around New York City will receive a more effectual treatment for their protection from corrosion than has thus far been accorded to any such structure in the past.

22. Inspection of work in progress shows quite as great a disregard of all the essentials to secure even a temporary protection from corrosion as any of the earlier methods for this purpose, the disastrous results of which are forcibly recorded in Brunel's tubular bridge across the St. Lawrence River at Montreal, the trusses of the Brooklyn Suspension Bridge, the New York City Elevated Railway, and many other important structures, hardly one of which presents a good example of protection from corrosion under even ordinary atmospheric exposure. Scores of tons of material, piled at many points along the line of the Rapid Transit Tunnel, show mill-scale plentifully present on the principal members of the columns, girders, and other parts, all painted over. Many parts, indifferently closed by the rivets, show them to be unpainted on their inner surfaces, and are of such construction that it is now impossible to coat their inner surfaces even by the action of a force pump. Hundreds of minor parts are painted in so careless a manner that the protective coating is but little better than a wash of brick dust, the curdled appearance of some of the coatings clearly indicating that the red lead paint had set before its application, and that the pigment is of an inferior quality. The greater part of this steel work is to be placed where it will be always damp or so walled in as to be inaccessible for inspection, or else exposed to an atmosphere always charged with tunnel vapors, with what effect upon its resistance from future corrosion the experience of the past can give but one answer.

Surely if the Boards of Admiralty of all the nations in the world deem the removal of mill-scale from the frames and plating of a hundred-ton steam tug of importance enough to resort to the pickling process for its removal before painting, those who are responsible for not only the construction, but the future condition and life, of a $30,000,000 tunnel could afford to adopt some better method of guarding the work against the disastrous results from future corrosion than that as now evidenced. The hydric sulphide in the combustion gases from the locomotives in use in any part of the completed tunnel, pending the inauguration of the electric motor power, will reach and destroy the red lead pigment regardless of what coating it is in, or in whatever amount it forms a part.

23. It costs as much to spread a poor paint over a structure as a good one, and the labor is generally from two to four times the cost of the paint. There is not difference enough in the covering power of different paints to allow it to be any factor in deciding between them. All paints will spread over about the same number of square feet of surface if they are of the same body or weight per gallon, and the same care is used in brushing them out, but the *hiding power*, or power to cover up a poor job on the part of the painter, or to mask the effects of corrosion already in place, lies almost exclusively in the iron oxide paints. Given a ferric structure to be protected from corrosion, the several parts after the machining processes and assembling in their relative positions in the workshop, and before a single rivet is driven or a bolt placed permanently in position, all scale, loose or tight, that the scraper, hammer, chisel, or steel brush can remove *should be removed, not scratched at*—better yet, sand-blasted. The latter need not cost over $\frac{1}{2}$ cent a square foot of large and small surfaces, and this process would remove the dirt and grease due to the machining processes. It is the painter's custom to brush the grease with benzine and spread it over a larger surface, and as the mixture is not wiped off dry with waste at once it dries down again, and the evil is only increased, the effects of the benzine on the surface aiding the evil. Turpentine is a better solvent agent than benzine, but that must also be *wiped off*, not allowed to dry down mixed with the grease. No paint applied over a grease coating will ever bond to the iron. The writer has removed skins of good elastic paint coatings as large as the hand from important members of a truss

which had been coated over machine grease for a number of years. Such places are a fruitful cause of corrosion, particularly pitting, as they are likely to be found in inaccessible places like the inside surfaces between tension tie bars, etc.

24. The first paint coating applied at the shop should be done in a dry, clear, warm atmosphere, either under cover or in the sun. Never paint iron in a fog or with frost in the pieces, even if to the eye they look dry. Glue applied to the warm surfaces of wood is 10 per cent. stronger than when applied to cold surfaces, and so will any paint cover and bond to the iron better if the surface is warm. The permanency of white lead mill marks on iron plates is due to this cause alone. It is a matter of no importance what the color of the first coating is, so that it is the *best* in quality of all those that are subsequently applied. A pure lampblack (not ground soot or bituminous coal) with boiled linseed oil can be ground and mixed for a light or heavy priming coat with the most satisfactory results in the protective qualities. This is true also of red lead and lampblack, a chocolate colored mixture, the two pigments uniting and working together when ground in the boiled oil as hardly any other two pigments are capable of doing, and there is hardly any other paint in which it is easier to detect adulteration. A small percentage of zinc oxide pigment works well with this red lead and lampblack mixture, and does not detract from its protective qualities for either wood or iron surfaces. It is probably as good a compound paint as can be mixed from a number of pigments not united as one body in its natural condition, but the influences to which any paint will be subjected must receive as much consideration as its composition. All paints containing red lead are extremely sensitive to the action of hydric sulphide, or the combustion gases from coal, as detailed hereinafter.

Graphite Paints.

25. The natural amorphous graphite pigments, particularly the Lake Superior brands, are distinctive in color, grind fine and granular, are amorphous in character, and indestructible as any pigment can be. They are wholly self-supporting as pigments, carry no elemental substances which tend to reduce them to a lower plane by oxidation or to slack in the presence of moisture. They require no body stuffing either to bond them or to keep them

quiet or from curdling or crawling during or after application. They are entirely different in character and composition from the many so-called silica graphite paints of commerce, compounded of flake graphite of more or less purity and of uncertain character with barytes, silica, furnace slag, and other substances. The several substances, even if the elements are non-corrosive or non-oxidizable, or if they are electrically or chemically passive of themselves or collectively, when assembled as a pigment are not as reliable or effective in a pigment as the same substances incorporated together by the processes of nature, each and every particle of which is of the same physical and chemical nature and equally affected by the menstruum, atmosphere, or other conditions that affect a paint.

26. The silica and graphite compounds have not the merit of being synthetical compounds, but are purely an agglomeration of substances as heterogeneous in character, with as many different specific gravities, as the contents of a spoil bank or gravel pit can furnish. Many of these silica graphite paints are composed wholly or in part of carbonaceous schists, and as pigments are not essentially different from soapstone and quite as repellent to the oil menstruum.

27. No human care in the mechanical processes due to the grinding, bolting, and mixing of the several substances in a compound pigment can arrange them in sequence in either the pigment or paint. The flake graphite is hard to grind other than in a flake form: the silica, barytes, and furnace slag are crystalline or vitreous in character, and grind and bolt as splinters or needles rather than in a granular or cubical form (the ideal form for a pigment atom), and have a tendency to mix with the oil in individual or by chance groups, instead of in a symmetrical whole as one natural granular compound substance would do. The flake graphite atom is a lubricant and is almost as repellent to the oil as it is to water, and does not carry well in the oil. The higher the percentage of carbon in the graphite the more these difficulties are developed. It is difficult to get hot glue to bond to a 90 per cent. graphite. It is one of the lightest pigments, specific gravity 2.77 to 1.21; while zinc white is 5.42; white lead, 6.43; red lead, 9.07; oxide of iron, 5.3 to 3.8; barytes, 4.7 to 4.3; silica, 2.8 to 1.9; chalk, 2.8 to 2.2; gypsum, 2.5 to 2.28; asphaltum, 1.8 to 1.4. The experience of master painters and paint chemists points to the fact that pigments of the great-

est density have generally proven to be the most durable. Flake graphite is hard to brush out alone in a paint, and the splintery character of the other substances assembled with it only increases this difficulty, as painters notice and complain about in the extra wear of their brushes, and the small area covered in a day's work. Flake graphite is easily adulterated with soapstone, specific gravity 2.7. Neither the eye nor touch can detect the adulteration in a pound of flake graphite ground with three pounds of soapstone—analysis only will show it. As well expect a paint compounded of powdered glass and soapstone to be durable as some of these so-called silica compound paints.

28. The natural drying of linseed oil in a paint or varnish is in the form of a closely woven web of a fine fabric. This shows plainly on the surface of a freshly dried or drying surface, and explains the reason why two or more coats are necessary to give a smooth foundation for the last or finishing coat. Each subsequent coat fills the interstices of that underneath it, the several coats mutually repairing the other's deficiencies, as successive folds of a fine muslin will, in the aggregate, make an adequate covering from heat or light. Now, it is the function of a pigment to fill these cellular formations in the drying menstruum, or rather, while being applied together with a brush, for the atoms of a pigment mechanically arranged by the brush to lie side by side, all embedded in the oil, which in drying naturally takes the lines of least resistance, *i.e.*, between the atoms of the pigment, so that, as it were, each atom lies in an approximately square hole, which is the most favorable condition for the bond between the pigment and its vehicle. But if the atom of the pigment be splintered like a sliver of glass, or of only length and breadth like a flake, then the natural cellular formations of the drying menstruum cannot be realized, and such pigments arrange themselves with the sharpest angles and edges upright to the drying surface, and are not well covered in or embedded in the oil. Hence they dry with a rough surface which holds moisture and dust which decomposes and quickly disintegrates them from their bed, and more moisture, cinders, and dust take their place to repeat their cycle of action on the atoms in the coatings beneath. A round marble does not bed itself as strongly in a cement as the cubical block from which it is made, neither does a beach-worn sand or a quicksand atom, with the best of cement paste, make a good mortar, for the same reasons.

29. An interesting contribution to the literature of protective coverings for iron is to be found in a pamphlet published by the *Railway Car Journal*, New York, 1896, being a translation from the German of a Prize Essay by Prof. J. Spennrath, under the auspices of the Society for the Advancement of the Industrial Arts, Berlin, Prussia. Some of the conditions and causes which lead to the destruction of paint coatings were reproduced by Prof. Spennrath in his laboratory experiments, but these only simulated the conditions of a paint exposed to actual service on a structure. Nineteen of the twenty experiments were with a *chemically prepared pure flake graphite* as a pigment, mixed with boiled linseed oil, presumably also chemically pure, though the professor is silent upon that point. The experiments were made on the paint skins as removed from the metallic plates on which they were dried, and were conclusive that certain acids and gases would destroy the menstruum of a paint skin coating of graphite and oil, but what the effect of these would have been had the skin not been removed from the metal is not stated. The professor evidently, from the paragraphs, page 21, preceding the record of his tests, had found the action of a coated metallic plate essentially different from that of a paint skin detached from its bond on the plate, and so far as the pigment was concerned in its relation to the oil as a protection from corrosion, the experiments might as well have been conducted with dried oil coating alone. The professor's experiments with the action of heat upon paint skins of various composition is quite as inconclusive of what to do to protect our ferric structures as his other reported chemical experiments. We do not expect our paint coatings to take the part and form of a loose tarpaulin covering, or to require an umbrella covering to protect them from the sun. There are many commercial paint and varnish compounds which successfully resist nearly all of the destructive elements detailed by Professor Spennrath, and it is to be regretted that his experiments did not embrace some of them, instead of the one flake graphite pigment he used, which cannot be had for a dollar a pound.

Graphite.

30. Graphite, in the many varieties of its foliated flake or amorphous forms, is found in all parts of the world and is of various degrees of purity, ranging in the foliated form from 60 to 99 per cent. of carbon, the purest brands, or those con-

taining the largest amount of graphitic carbon, being the lightest. Its specific gravity ranges from 1.21 and 1.40 to 2.255 and 2.768. The Ceylon, Cumberland, Indian, and American varieties are remarkably pure, and are used principally for pencils, crucibles, lubricants, stove polish, and to tone up the Siberian, German, and other poorer varieties for the many purposes of the day, which have developed a branch of manufacture second to none in energy, skill, chemical knowledge, and trade requirements.

In this article we are dealing with graphite as a pigment, and however suitable a foliated graphite may be for a pencil, crucible, or lubricant, its use as a pigment, for the reasons mentioned before, is not as satisfactory as the amorphous variety, which, less rich in carbon, contains other substances non-corrosive, non-absorbent of moisture and gases, either individually or collectively as a granulated natural compound. That this point may be duly considered, when a pigment is to be selected for ferric structures, we give the following analyses of amorphous graphite from three widely separated mines:

	Siberian and German Mines.	Lake Superior Mines, U. S. A. Detroit Graphite Mfg. Co.
Carbon (graphitic)	33.20 to 36.06	28.39 to 38.48
Silica as SiO_2 (combined)	43.20 " 37.70	46.97 " 37.54
Iron soluble as Fe_2O_3	3.05 " 4.02	4.22 " 14.25
" insoluble as Fe_2O_3 (combined)		
Alumina as Al_2O_3 (combined)	15.42 " 17.80	16.90 " 12.35
Calcium as Ca_2O_3	1.06 " 1.20	0.99 " 1.02
Magnesia as MgO (combined)		
Carbon dioxide, combined water, sodium compounds, volatile matters, iron pyrites, and loss	4.09 " 3.22	2.53 " 1.86
	100.00 to 100.00	100.00 to 100.00

These minerals grind and bolt in a granular and approximately cubical form, are not repellent of the oil or vehicle, are nearly as unoxidizable from moisture and atmospheric influences, combustion gases, etc., as pure carbon; are of an agreeable color of themselves as pigments, work well in combination with other colors, flow well under the brush and cover as much surface as any other good paint; do not separate from the oil in the paint pot or barrel in storage, are prepared ready for use, and cost less per gallon, and will last longer when properly applied to a ferric structure than any pure flake graphite pigment, which was the base of Professor Spennrath's experiments. They are prac-

tically indestructible by any heat less than that which would char the oil (500 degrees Fahr.).

31.* Boiler tubes coated with the Superior Graphite brand of paint having been exposed to internal firing and hot water action under constant working pressures of eighty or more pounds per square inch for two years, have kept their coatings uninjured and as fresh as when first applied. Pieces of iron coated with this brand of paint have been dipped in muriatic, sulphuric, and oxalic acids, and then allowed to dry with the acid on them for nineteen days without showing a trace of any damage to the paint. Other protective oil paints subjected to the same tests were utterly destroyed in twenty-four hours. Superior Graphite paints have been immersed in strong solutions of sal-soda and ammonia for nineteen days, and in coal oil for several weeks, without showing injury. Tested in boiling alcohol, boiling beer, boiling brine, boiling sugar and water, cold soft soap for twenty-four hours, they remained uninjured, while other protective paint coatings exposed to the same tests were destroyed in from fifteen minutes to one hour. These results were produced by specially prepared samples for the several special requirements to which the coating was to be subjected in service, but the pigment base of the paint was in all cases the ordinary stock of commercial Superior Graphite paint sold in the open market by thousands of barrels yearly.

32. While tests of special paints are not regarded by many engineers as indicative of their value to resist the ordinary conditions of a coating exposed to weather, they do show that paints which can withstand these severe tests are certain to give more satisfactory results in general use on any ferric structure than the many competitive and cheaper coatings whose low price, and not their protective results, is their principal recommendation. They also show that if the conditions are known to which a coating is to be subjected, it can be generally furnished to meet them successfully. That the strictly commercial brands of the Superior Graphite paints appear to be as thoroughly reliable protective coatings for ferric structures exposed to weather under the various conditions to which such bodies are generally subjected as are the special brands of

* *Trans. A. S. M. E.*, 1894, vol. xv., paper No. 598, pages 1072, 1073; also 1895, vol. xvi., paper No. 637, page 700.

paints above mentioned is evident from the following examples selected from scores of instances of their application:

33. The Union Station railway viaduct over the Michigan Central Railroad at Detroit, Mich., erected in 1891–92, was painted with red lead, which utterly failed within two years, owing to the smoke and steam from the locomotives in constant service beneath it. About one-half of the entire structure, comprising the most exposed and badly injured portions, was repainted in 1894 with *one coat* of Superior Graphite paint, and is, at the present date, in as perfect condition as when repainted, and will evidently remain so for many years. The failure of the red lead coating could have been foreseen, had the engineer in charge considered the fact that an oxide of lead coating exposed to gaseous acid or hydric sulphide (always present in the gases of combustion) *by the inexorable laws of chemistry* changes the oxide of lead to a sulphide of lead, whose volume is 33 per cent. greater than the oxide from which it was formed, this change taking place while the oxide is embedded in the dried menstruum. No wonder that the red lead coating failed here, as it will in all other locations in the presence of hydric sulphide, hot or cold.

34. The structural and covering steel work of blast furnaces, the rolling mills and other workshops connected with manufacturing steel plants, are particularly exposed to the attack of this gaseous acid, and where the protective coatings have been red lead, it has always failed after a brief existence, and always will.

The engineer of a prominent Western steel plant, after a thorough test of ten different paints, extending over three years, abandoned the use of red lead, and all other competitive paints, selecting the Superior Graphite paints for the blast furnace and all other buildings of his company, also for repainting the old ones.

35. An important railway bridge over the Monongahela River at Pittsburg is in a particularly exposed position, subjected constantly to an atmosphere heavily charged with moisture almost amounting to a perpetual fog, charged with the sulphurous fumes from passing steamboats, and the manufactories in the city. It was painted in 1896 with Superior Graphite paint, which is to-day in perfect condition, and will not need repainting in many years.

36. The double deck bridge of the Chicago, Rock Island and Pacific Railroad, over the Mississippi River at Rock Island (the

largest bridge over that river), was coated in 1897 with Superior Graphite or L. S. G. brand of commercial paint, selected by the railway and the United States Government engineers in charge of the work after an extended examination and test of many paints in competition. The present coating of this bridge is perfect in all respects, though in an exposed situation, and subjected to the unusual conditions of a railway, animal, team, and footway service.

37. The structural steel work of the United States Government Printing Office at Washington, D. C., the Waldorf-Astoria Hotel, and the Metropolitan Life Insurance Building in New York City, all ranking among the largest, best designed, and constructed buildings in the world, are all painted with Superior Graphite paints, selected from many competitive paints, after long and exhaustive tests of the same by the architects and engineers in charge of their construction. The same can be said of scores of other large and first-class modern steel structures in New York, Boston, Philadelphia, Chicago, and other cities. The Superior Graphite paints have been selected as coatings in almost every case after competitive tests with other ferric coatings.

38. These favorable results, following the use of this brand of graphite paints, have been taken almost at random from hundreds of applications to all kinds of structures, large and small, and under all possible conditions of exposure. They cannot be deemed accidental results, but must rest upon the superior quality of the amorphous graphite pigment, the well selected and carefully prepared menstruum, the thorough methods of manufacture, all combined to produce a homogeneous reliable product, which is not due to any haphazard combination of fortuitous events.

39. Parties in interest as users of large quantities of paints ask why the Lake Superior amorphous graphite furnishes a pigment superior to other brands richer in carbon either as an ore or combined with free silica. The qualities of an artificially combined carbon and silica pigment are given elsewhere in this paper. With a natural graphite ore, the larger the percentage of graphitic carbon, the lower is the percentage of silica combined with it, the other combined substances, about 20 to 24 per cent. (see analyses), remaining approximately the same. If the combined silica be wholly replaced (or nearly so) by the carbon the ore becomes greasy to the touch, does not grind

well, is repellent to the menstruum, does not spread well as a paint, and when the menstruum is weakened or affected by causes due to elemental or other effects, and the pigment atom is exposed, its bond with the menstruum and to the surface on which it lies or is in juxtaposition is weak by reason of its repellent nature, and it is soon washed out, and a porous coating results which hastens the decay of the whole coating. Experiments show that graphite ores containing 60 or more per cent. of graphite carbon *are not* any more, if as durable pigments, when exposed to either chemical or natural decay, as those containing lower amounts of carbon. A graphite or other mineral atom will bond better to the menstruum, and to the surface over which it is spread, when the percentage of the metal or substance that forms the base of the mineral is low.

Asphaltum Coatings.

40. The so-called asphaltum paints in general have thus far proved to be quite as ineffective as protective coatings as any of the iron oxide or miscellaneous compound paints. Their name is a misnomer, as few, if any, contain 5 per cent. of asphaltum, and even that amount is seldom treated to free it from the vegetable matter and acids with which it is associated in its natural state, and, as a rule, the substances incorporated with it as pigments are quite as carelessly chosen and uncertain in composition as the asphaltum itself, which is simply the residual from evaporated petroleum, and contains in its natural state often as high as 10 per cent. of sulphur. Benzine and bisulphide of carbon (made by passing the vapor of burning sulphur over burning charcoal) are generally employed as solvents of the asphaltum in the preparation of the menstruum, and whatever pigments are incorporated with it, they are more or less affected chemically by the bisulphide ingredient. They are in no respect a synthetical mixture, either in the pigment or paint, but are mechanical haphazard compounds drying by evaporation instead of by resinification. Its name is a catchy one to conjure with, and to sell the product, and its use should be confined to the many minor ferric constructions of the day, but not allowed on the more important structures, whose condition should be always above suspicion of corrosion. Its low price is a strong element in its favor with purchasing agents and

indifferent bridge painters, where quantity rather than quality governs. A moderate price in a bridge paint usually denotes a moderate or no result in a protective sense.

41. Bitumen, asphaltum, and other varnishes, *not paints*, have not received the attention from engineers and other persons responsible for the care and protection of our ferric structures that their merits deserve. This is probably owing to their high cost. The skill required in their preparation debars the average paint compounder from attempting their manufacture, and more care is required to apply them than the cheap painter will give.

42. A notable instance of their efficiency when well made is afforded in the case of the steamer "Glenarm," used in the coasting trade between Scotland and England, that was wrecked in 1895. (For full report see *Engineering*, July 13, 1896, pp. 157, 158; also *Transactions* American Society Mechanical Engineers, vol. xviii., 1896, paper No. 713, pp. 251–289.) This ship, carrying 650 tons of burnt iron ore or residuum from the manufacture of vitriol, was beached to prevent total loss. She was submerged to her deck for *only six days*, when she was pumped out and raised. All of the bright iron surfaces of her engines and the inside surface of the steam cylinders and chests, donkey pumps, boilers, etc., were corroded and softened from $\frac{1}{32}$ to $\frac{1}{8}$ of an inch, and required to be remachined in all their parts. All the copper pipes were affected, many were renewed. The composition metal in the valves, packing rings, etc., appeared as though the zinc in the metal had been sucked out. Every 100 tons of the burnt ore carried corrosive agents which would have dissolved at saturation thirty-two hundredweight (3,584 pounds) of iron, or for the whole cargo 21,504 pounds. How much iron in the ship and machinery was actually dissolved in the short period of her immersion is unknown, but it must have been considerable from the effects upon her machinery as above stated. What would have been the effect had the immersion been 30 or 60 days can only be conjectured from the fact that the bolts and nuts, hammers, spanners, firing tools, and all small and loose iron parts were wasted away to a semblance and required renewal. The shaft journals, crank pins, and all exposed parts between the boxes and housings were badly corroded, and required remachining. The machinery part of the vessel, other than its bright or moving parts, was painted with *red lead and boiled oil;* the walls of the engine and fire room and passages

were painted with *white lead*, and *both were unaffected by the corrosive bath*. All parts of the journals which were in actual contact with other metal, but with a film of heavy lubricating oil between them, were also uninjured. The framework, inside skin of the vessel, coal bunkers and cargo bulkheads, etc., were uninjured, though exposed to the full strength of the solution from the corrosive cargo, as the sea water here had no change from the tides as in other parts of the vessel. These parts were coated with James Ritchie & Sons', Limited (Belfast) anticorrosive bitumen varnish (*not paint*), manufactured from pure bitumen freed from organic acids, etc. This was an extraordinarily severe test for any coating, and while not likely to occur once in a thousand instances, yet the coating that has endured it successfully is a good one to adopt for any ferric structure.

43. A similar composition of varnish to the above (Ritchie's) is manufactured by Edward Smith & Co., under the name of "Durable Metal Coating," composed of asphaltum, Kari gum, linseed oil, and turpentine, compounded by a moderate and long-continued heat, until the several substances are thoroughly incorporated together, and the albumen and other impurities are removed by evaporation or deposit. This coating contains no pigment or foreign substance in its composition, is strictly a varnish, and, as a protective coating applied with a brush, is secondary to none. The best results are obtained from its application when the material coated and the compound itself are moderately warm, as in the sun on a hot day—a result that is equally noticeable with any good oil paint.

44. The literature of protective coatings has been greatly enriched by Edward Smith & Co.'s publication as a trade catalogue of the discussions on "Protective Coatings for Iron Work," by Prof. A. H. Sabin, M.S. (Member of the Society and late Professor of Chemistry in the University of Vermont), read at a meeting of the New England Railway Club, Boston, Mass., and before the American Society of Civil Engineers, New York, 1895. It is possibly a too radical departure from the old-time methods of protecting ferric structures by the paint brush and a pot of some sort of compound called paint for many engineers, either in construction or in charge of repairs, to consider the merits of a baked japan coating such as is described by Professor Sabin, under the name of "Baked Coating," which has proved to be so reliable to prevent corrosion under hydraulic and underground

tests. The process is peculiarly adaptable for all the chord eye bars, lattice posts, struts, and other members, which in position are so closely set together, or from their lattice box form, that their actual condition on the inside surfaces can never be ascertained, only guessed at, and can never be either inspected, scraped, or repainted in such a manner as to insure their being absolutely protected against corrosion which, once established, must proceed, and this, too, on the very parts of the truss on which its strength is dependent. From the disturbed condition of the iron or steel at the eyes of the chord bars due to the operation of forging, the metal at these points is affected and not in its normal condition as relates to the body of the bar, which is as it left the rolls. These eye bars have been found to be unequally affected by the local galvanic action set up in all bars of iron or steel under stress, and become electro-positive at or near the eyes and welds where the metal has been most disturbed in forging, and this action seems to concentrate the corrosion at those points if there is any deficiency of the protective coating at or near these points to localize it. The electromotive force between the body and eyes of a tension bar has been found to range from 0.003 volt to 0.023, 0.019 being that due to soft Bessemer steel, from which such bars are generally forged. The position of these bars as to their magnetic polarity has been found to manifestly increase this electromotive force at times to nearly double these amounts, and this ever present element always ready for duty may be the agent which has caused some inexplicable instances of corrosion like that where 5-inch by 1-inch bars have corroded beyond the limit of safety, and other instances where holes nearly an inch in diameter could be cut through the bar.

45. The edges of all channels, angles, tees, and other special truss forms are a well defined round, and when closed together or to plates or bars in the many types of bridge construction, form at their intersection a reëntering angle or groove, instead of a salient one. Besides, the rough edges of these forms and this rough reëntering angle are hard to paint, as the paint will not flow down into them of its own volition, and the painter is generally too careless to fill them with his brush even if the confined strip of air did not refuse to escape as the paint-loaded brush is drawn over it or slapped on it. Particularly is this the case if the surfaces are cold or damp. These places are not

few in number and of no moment, but are to be found by hundreds of lineal feet in any structure of magnitude, and are almost invariably the seat of corrosion. They are seldom scraped out in repainting the structure; the ballast and street dust, cinders and ashes from the locomotives find ready lodgment at these points, and are not washed out by the storms, only kept moistened and ready to commence their corrosive work at the earliest moment possible. The destructive carbonization of bituminous coal for coal gas, or for hard foundry coke, only eliminates about one-half of the sulphur in it, the other half being found in the resultant coke. About one-half of this remainder is consumed in the high heat of the locomotive fire box, and the balance is found in the ashes and cinders. The soft coal used on many railway lines often contains 4 per cent. of sulphur, and a solution from the ashes and cinders is strong enough to redden litmus paper. Small wonder that many bridges are in an advanced state of corrosion within ten years of their erection.

46. There is nothing impracticable in applying a baked japan coating to all these parts of a railway truss, except, possibly, the end posts and top cords which require to be riveted up in position. The floor beams, stringers, etc., could receive the same treatment, while the added protection from this process manifest in the lessened amount for materials and labor in the frequent repainting of the structure, would probably equalize the cost as compared with paint within comparatively a few years.

47. Whatever its cost per square foot of surface, there is no doubt that all parts of the iron work used on the underground railway system now under construction in New York City, which is covered in and out of sight, and cannot be readily inspected at all times, should receive a baked japan, or other enamelled, or Bower-Barff coating, particularly the roof girders, beams, and covering plates, as well as all the iron, which is embedded in mortar or cement, which in these locations will always be moist, so that caustic action from the lime, mortar, and hydraulic cement will disastrously affect the ordinary oil coatings in contact with them. Once closed in, there is no remedy for corrosion except another upheaval of our city streets, and an added burden of discomfort and debt, which in all reason with our past engineering experience applicable to the needs of the day, we ought to be able to avoid without a special act of the Legislature, or the consent of a political boss.

48. In a paper read before the Newcastle, England, section of the Society of Chemical Industry, Mr. Henry Smith, F. I. C., described a series of experiments upon the protective powers of 27 different English commercial paints, as applied to iron work in 50 separate instances. Reprinted from the *Engineer* (London), by the *American Gas Light Journal*, September 4, 1899. The methods of test were those devised and employed by Mr. Max Toltz, C. E., in a series of experiments upon a number of American commercial protective coatings for iron, the deductions being embodied in a paper read by Mr. Toltz before the Society of Civil Engineers, St. Paul, Minn., and reported in the Journal of the Association of Engineering Societies, 1897, reprinted in the *American Gas Light Journal*, September 20, 1897. Three sets of bright and clean iron plates, all of the same size, were respectively coated with the several paints, in all cases furnished as a stiff paste in the proportions of pigment and oil, as herein given, and when applied were brought to the consistency of a paint by mixing with genuine boiled linseed oil, capable of drying in *seven hours under ordinary conditions of temperature*, no driers or turpentine being used. The first coat was allowed to dry thoroughly firm before the second coating was applied. When this was firm and hard, one set of the plates was exposed to the weather, as in ordinary cases of painted structures. The other two sets were treated as follows: One set was simply to corroborate the results obtained from the other set; the results being practically identical in each case. Each painted strip was placed in a clean, wide-mouthed glass bottle, half filled with clean, pure water. The bottles were not closed, but were protected from the entrance of dust and impurities while allowing the air free access to the painted plates. Several of the plates had commenced to corrode in about a week. This was indicated by a cloudiness in the water, which afterwards became further oxidized, and formed a red precipitate of ferric oxide or rust, which subsided partly to the bottom of the vessel. After three months' exposure the plates were removed, and the liquid in each bottle together with the sediment was tested for the percentage of iron present in the form of rust.

49. The figure given as denoting the amount of corrosion is less than the actual amount, as it does not include the portion that adhered to the plate, which was not scraped or brushed to remove the portion that would not drain off. In each case the weight of rust was calculated to pounds of rust per 1,500 square

yards of painted surface; the other figures give the percentage composition of the several paints by weight.

CONDITION AFTER THREE MONTHS' EXPOSURE.

Pounds of Rust from 1,500 Square Yards of Surface.

					Corrosion.
6 samples of red lead alone, or mixed with barytes 50%			raw oil,	10.00%	None.
Red lead.....22.00%; barytes, 66.00%; total.. 88.00%;			" "	12.00%	"
" " .....33.33%; " 58.80%; " ...92.13%;			" "	7.87%	"
3 samples zinc oxide, " 45.00%;			" "	10.00%	Trace.
Zinc oxide.....27.27%; " 63.63%; " ...90.90%;			boiled oil,	9.10%	"
White lead, pure 92.56%;			" "	7.44%	75 lbs.
White lead....53.78%; " 40.33%; " ...94.11%;			" "	5.89%	80 "
" " ....50.52%; " 42.10%; " ...92.62%;			" "	7.38%	95 "
Iron oxide, pale (50% Fe_2O_3).. 83.60%;			" "	16.40%	81 "
" " deep (96% Fe_2O_3).. 86.89%;			raw oil,	13.11%	123 "
" " venetian red..... 7.55%					
Barytes 80.57%	" ...88.12%;		" "	11.88%	123 "
Iron oxide, medium color (94% Fe_2O_3) 86.89%;			" "	13.11%	134 "
Iron oxide, extra bright color (90% Fe_2O_3)..... 82.35%;			" "	17.65%	127 "
Iron oxide, pure (90% Fe_2O_3)... 76.30%;			" "	23.70%	160 "
" " medium..... 12.30%					
Barytes 76.22%	" ...88.52%;		" "	11.48%	244 "
Indian red (70% Fe_2O_3)..... 82.35%;			" "	17.65%	227 "
Turkey red (95% Fe_2O_3)..... 81.16%;			" "	18.84%	262 "
Iron oxide..... 27.03%					
Barytes and calcium carbonate. 62.52%	" ...89.55%;		" "	10.55%	398 "
Barytes (natural barium sulphate)..... 88.00%;			" "	12.00%	155 "
Iron oxide, venetian red..... 8.47%					
Barytes and calcium carbonate. 78.80%	" ...87.27%;		" "	12.73%	118 "
Iron oxide..... .... 13.93%					
Barytes and calcium carbonate. 60.00%	" ...86.07%;		" "	12.14%	242 "
Rose pink (principally barytes). 12.14%					
Barytes and calcium carbonate. 80.56%					
Celestial blue..... ..... 11.83%	" ...92.39%;		" "	7.61%	266 "
Barytes and calcium carbonate, 68.99%					
Ivory and carbon black..... 8.42%	" ...79.87%;		boiled oil,	20.13%	352 "
Manganese dioxide..... ... 2.46%					
Barytes and calcium carbonate, 79.30%					
Carbon and bone black..... 4.35%	" ...84.95%;		raw oil,	15.05%	392 "
Manganese dioxide..... 1.30%					
Drop black (charcoal black)....60.00%;			boiled oil,	40.00%	250 "
Flake graphite, pure.....69.56%;			raw oil,	30.44%	215 "
Boiled linseed oil, pure.....					500 "
Raw Turkey umber.....51.85%;			raw oil,	48.15%	510 "

Twenty mixtures of barytes alone, or with calcium carbonate mixed with Celestial blue, Prussian blue, chrome yellow, raw sienna, Vandyke brown, Italian ochre, Brunswick and other greens, chromate of lead, English umber, Turkey umber, ultramarine, Chinese blue, burnt sienna, mixed with raw oil in proportions from 11 per cent. to 51 per cent. of the weight of the paint; the corrosion in the order named above ran from 168 pounds to 441 pounds per 1,500 square yards of surface.

50. Except in the case of the blues, umbers, siennas, etc., where the pigment had but little influence on the oil to resist decay beyond that inherent in the oil alone, the more separate substances that entered into the composition of the pigment, the more unreliable it became. A single exception is noted in the case of a Venetian red paint, made from barytes, calcium carbonate, and a small amount of iron oxide, that gave a better result than barytes alone, or when barytes was mixed with the other color pigments of much less specific gravity. Several substances in a composite paint are generally fatal to its protective qualities no matter to what it is applied. The several atoms of these substances, even if uniformly distributed in the pigment in the process of grinding, bolting, and mixing (but they are not), will retain their juxtaposition; when mixed with the oil, only momentarily, the heavy atoms will sink, and there will be a marked difference in the coating spread from the top of the paint in the pot from that in the middle or bottom; the lighter and most perishable substances will get on the surface first.

51. Barytes worked well with red lead and zinc oxide, there being but a small difference in their specific gravities as compared with barytes and the other color or base pigments. With white lead, as the percentage of barytes was increased, so was the corrosion. Aside from the reduction in cost of these lead and zinc pigments by the addition of barytes, there is no reason for its use, as the barytes alone did not give a satisfactory test. No doubt from the splintery character of its atoms, as has been before commented upon, it is wholly destitute of covering or color power. The vagaries of the iron oxide paints in the varying proportions of the pigment and oil are noticeable, but not so marked as where barytes, one of the heaviest of all pigments, and calcium carbonate, one of the lightest, both classed as inert pigments, were mixed with the oxide, and fully sustain the previous remarks upon the non-protective character of composite

and iron oxide paints. Boiled oil, in the single instance reported, proved superior to raw oil as a vehicle for the several iron oxide paints in the ratio of one to nearly five.

52. A second series of experiments were made by the same experimenter, and following the method of Mr. Max Toltz, C.E., to wit: A number of iron dishes five inches in diameter and one-half inch deep were scoured bright, and then coated with two coats of the several paints used upon the above-detailed iron plates and under the same conditions as to the composition and drying of the paints. These shallow dishes were filled with water and allowed to completely evaporate in the open air of the laboratory. This operation was repeated six times in the course of six months. Thus tested, the only paints which remained practically unaffected were red lead and orange lead paints, some of which, however, such as the "vermilionette" and scarlet red paints, contained also a proportion of aniline colors, whilst two of the red lead paints contained in the one case 45 per cent. of barytes and in the other 66 per cent. All the other dishes were more or less rusted, the order of merit of the better paints being as follows:

1st. Zinc oxide.
2d. Equal parts zinc white and barytes.
3d. Zinc white, 3 parts; barytes, 7 parts.
4th. Lithopone (a mixture of zinc sulphate, zinc oxide and barytes).
5th. Pure white lead.
6th. White lead, 5.37 parts; barytes, 4.03 parts.
7th. White lead, 5.05 parts; barytes, 4.21 parts.

All the other paints, thirty-six in number, proved inefficient. The first to show rust was that one painted simply with linseed oil. The above classification of merit is by Mr. Smith, and, taken together with the detailed report of the glass bottle test (before given), may be considered a fair representation of the protective qualities of the hundreds of commercial paints foisted upon the market under various trade-mark names in the United States as well as in England, where the above experiments were conducted.

53. Both the immersion and dish tests are very important for determining in a relatively short time the weather-resisting power of a paint. If the coating is unable to resist the action of water or moisture in the form of steam, fog, or vapor from a

tunnel or other confined space, it cannot be desirable for the protection of a ferric structure, or even a wooden one. The dish test probably is the nearest to the actual condition which a paint must withstand. When the water in the dish is nearly evaporated, there remains in the circular seam of the bottom a film of water which contains the carbonic acid and the decomposing gases and dirt from the atmosphere, which acts upon the paint in such a way that the coating at that part is soon permeated and rust forms. This action is more and more developed after each evaporation, and practically covers the whole dish in a short time. In actual service the same thing will happen. The corner of the dish finds its counterpart in every corner of a ferric structure where two plates, angles, or other parts join. Rust will commence at those seams and extend under the paint, but will not show as plainly on a bridge truss as on the small dish. The shallow dish tests by Mr. Max Toltz, C.E. (before referred to), were made prior and during 1897, and extended over a period of from six months to two years. Without entering into as great detail as that quoted from Professor Smith, the deductions from his tests are in brief. Twenty-two different paints were submitted to test under the following classification:

No. 1. True asphaltic varnish paints compounded by heat in the same manner as a black baked japan, and practically of the same nature and comparable therewith. No corrosion reported after the dishes had been filled and evaporated naturally fourteen times.

No. 2. So-called asphaltic varnishes, or paints of inferior qualities to the above No. 1, made from asphaltum dissolved in benzine or other volatile menstruums, *but were not a true varnish.* They contained about 43.5 per cent. of vehicle and 56.5 per cent. of asphaltum. As a rule they showed well in the beginning, but after the volatiles had evaporated, especially when subjected to a moderate heat test, the coatings became quite brittle, were easily removed by abrasion, and did not protect the surface covered with them. Their composition varied in the several specimens tested. One sample analyzed had *no asphaltum* in it. Under test the dishes painted one coat showed considerable rust all over after the fifth exposure. Those painted two coats, after the seventh exposure showed not much better. Generally their reliability as protective coverings for ferric structures is the least satisfactory of all paints.

No. 3. Black carbon paints, in which the vehicle was practically a varnish, the carbon black and other pigments being ground in a practically linseed oil varnish, and are comparable with No. 1, to which they are closely related. The dish painted with only one coat showed a little deterioration at the end of the fourteenth evaporation, while the dishes painted two coats were uninjured, the coating being as elastic and tough as when first applied.

No. 4. Iron oxide paints consisting of more or less iron oxide with more or less silicious matter, and compounds of lime and magnesia. They were of different grades and qualities, were as a rule well ground and spread well. Under test the dishes painted one coat, after the fifth exposure many rust spots appeared. Those painted two coats were refilled six times, and on them the rust was plainly discernible to the eye.

No. 5. Graphite paints and silica graphite compounds. These paints were received from the several manufacturers in the form of a stiff paste, and when mixed, ready to apply, 4½ parts of paste to 3½ parts, by weight, of boiled linseed oil were used. The dishes painted with one coat were evaporated ten times. After the fifth evaporation a few specks of rust were noticeable, and the number gradually increased after each successive evaporation. After the tenth exposure some slight difference between them was noticeable, but not much. The dishes painted *two coats* were exposed thirteen times in two years, and none of them showed any rust or indication of rust. The natural toughness and elasticity of the paint still remained.

54. It will be noted that there is a wide discrepancy in the results of the dish test of Mr. Toltz, as above, of the graphite paints, both the natural amorphous pigments and the compounded silica graphite pigments, and the plate test given by Professor Smith of *pure flake graphite* mixed with *raw linseed oil* that gave 215 pounds of corrosion to 1,500 square yards. This, no doubt, is due to the repellent nature of the pure flake graphite; the pigment does not take kindly to the oil, no more than soapstone does. Raw oil, even if pure, contains over 7 per cent. of water, that renders a combination of the graphite and oil quite uncertain unless under the influence of heat. The boiled oil vehicle with pure flake graphite, used by Professor Spennrath in his experiments (before referred to) with paint skins detached from the metal surfaces, withstood an exposure

in a pure water bath for six weeks without injury other than a slight loss in weight of the skin. Moisture in the oil in this case was eliminated, as in the case of Mr. Toltz's graphite paints, and the merits of boiled oil as a vehicle for most paints over raw oil is sustained in these experiments, as it is in daily practice elsewhere.

55. The result of these tests corroborate the series of tests made by order of the Secretary of the United States Navy in 1884–5.* By request, sixty paint firms submitted seventy-five different paints for test, which were applied to five hundred test plates, and then immersed in sea water at four navy yards, and upon one government vessel in service. The paints that successfully withstood the test and received an *order of merit* were red lead, zinc oxide, carbon, and graphite compounds. The so-called asphaltum paints were at the bottom of the list in the *no merit column*. Evidently there has been slight improvement, if any, in this class of paints since the date of the U. S. Navy tests to the present time, and one can but wonder, in the face of repeated and recorded failures, that they ever receive an application to a ferric structure, ashore or afloat. Lead, zinc, carbon, and graphite compounds maintain their supremacy for government work, and particularly the amorphous Superior Graphite paints that have been selected by the Navy Department for the war color of our battleships and other war vessels, and for the gun carriages and other ferric bodies that line our thousands of miles of coast defences. In other tests of commercial and special paints, where the tests have been carried to the destruction of the coating as a whole, the partial destruction of the menstruum was generally followed by the disintegration of the weaker substances comprising the pigment, such as the carbonate and sulphate of lime, asphaltum, iron oxide, and the various color pigments, viz., the ochres, umbers, blues, greens, carmines, yellows, etc. The only pigments practically unaffected by the destructive element were the graphites; the silica, barytes, slag, slate, brickdust, and other adulterants were but little affected, some of them being partly recoverable, which was also the case with the red lead, white lead, and zinc oxide pigments. Pure water is a greater destructive element to an oil coating than solutions of sal-ammoniac, or chloride of magnesium, common salt, or natural sea water, if free from sewage, all of which are generally classed as agents of destruction.

* *Trans. A. S. M. E.*, 1894, vol. xvi., paper No. 625, pp. 399–402.

The salt decreases the action of water on an oil coating, the destruction of which is hastened by mechanical action if the water, either fresh or salt, or the other solutions, are in motion. Ordinary commercial oil coatings are destroyed by diluted muriatic and nitric acids, alkaline liquors, ammonia, sulphide of ammonium, soda, caustic alkalies, and alkaline solutions of coal ashes, clinkers and cinders, soot, etc. Diluted sulphuric acid does not materially affect an oil coating. All gaseous acids destroy the coating quicker than the acids in diluted aqueous solution, the destruction being in all cases hastened by heat or motion. Hence, to determine the probable protective value of any paint or other coating, it is necessary to know the detrimental influences to which it is to be subjected.

56. Objection is made by some engineers and paint manufacturers to these methods of testing paints; that they do not meet the actual conditions of coatings exposed to weather; that a ferric structure is not always wet, but wet and dry, with more dry hours than wet, etc. This would depend altogether upon the location of the structure, and in many instances there might be more wet or damp hours than dry ones. A fog or long-continued sweat is more destructive to a paint coating than a passing storm. But the plain fact remains that these tests (and many others, the details of which are not given) are all competitive as between different commercial paints, and under uniform conditions. The trial given one paint was given to all; the few successful ones that head the list are the better ones to select from to base any subsequent improvements or experiments upon, or for use. One manufacturer remarked, when the result of the test was given him: "If I had only known that my paint was to have been subjected to any such test I would have furnished a different sample." Just so, and it *would not* have been such as he was selling, possibly under a catchy trade-mark name, at a high price per gallon, with loud claims for its superiority. The water test settles the merit of a protective coating in short order, and so soon as generally adopted by those ordering paints for the protection of ferric structures exposed to weather, so soon will the great majority of these patent paint compounds cease to vex the engineer with high claims and low performance.

57. The nearer any protective coating approximates an enamel or varnish, generally the more durable it will be. The Japan and Chinese lacquers are varnishes, and dry better by the application of water than in dry air alone, and all compounded varnishes are

hardened in the last stages of their drying by water. Lacquers, when thoroughly dry, remain unchanged for scores of years, when exposed to either fresn or salt water, hot or cold, alternately wet and dry, or immersed. The coming ferric protective coating will probably be a true varnish with a carbon or graphite pigment. But it will be well to bear in mind that it will not be imperishable in exposed locations, and that its application and the preparation of the structure to receive it will require more attention than at the present time these matters generally receive, neither will it be a low-cost article.

58. Stress is laid by many engineers and master painters upon the fact that the use of raw oil in a paint allows it to be applied to a surface that is moist, damp, or frosty, with better results than when the oil is boiled, as the raw oil, having more or less water in its composition, naturally will take up an added portion which is on the surface being coated; hence the additional moisture is of no moment, as it would be in the case of boiled oil, in which most of the moisture has been expelled in the process of boiling, and when so expelled and cold refuses to take up again any noticeable amount of water *when a pigment is present.* All the moisture in any paint vehicle, be the same more or less when the paint is spread, must be eliminated by evaporation alone; not an atom of it enters into the resinification or drying of the coating. This evaporation of the water, whether that contained naturally in the raw oil or the added amount striven to be incorporated with it by the paint brush, in the process of drying, must escape as a vapor of more or less tension; its exit through the vehicle, be the same more or less elastic, as all drying vehicles are, can only be as a vapor, and not as a liquid, in drops however minute. This outward passage of vapor leaves the menstruum porous, and where moisture can pass out, moisture can go in; there is nothing in the nature of a porous drying menstruum that takes the function of a a back-action check valve to keep moisture out. If the coating has hardened externally by evaporation or resinification before the temperature of the coated body is raised to that degree to allow the vaporous moisture to escape, then its course is reversed, and the moisture will be found next to the coated surface, whether it be of wood or iron; the coating as a whole is pushed up and a blister formed, which in the case of a ferric body always denotes the first step towards corrosion. Again, raw linseed oil consists of oleic, margaric, and stearic acids, united to a common base,

glycerine. This base is hygrometric, and unites completely with water or moisture in any proportion presented to it, whether from the atmosphere or other sources. When various pigments, such as the salts of lead (lead carbonate, lead hydrate, etc.), are ground with raw oil, these salts unite chemically with the oleic acid to form linoleate of lead. As a consequence of these decompositions in linseed and other siccative oils, the margaric and stearic acids (called fatty acids) are set free, likewise the base, glycerine. The fatty acids are absorbed by the linoleate of lead (or lead soap); the glycerine, however, does not unite chemically therewith, but is merely suspended in the soap mass, which, as it gradually absorbs oxygen from the atmosphere, hardens into a skin, and as the hardening proceeds, the glycerine is gradually expelled from the lead soap, and with its load of moisture will be found under the skin of drying oil or paint as a blister loaded with the oxygen necessary to establish a full-fledged product of corrosion.

59. There are other salts of lead and other pigments which absorb a great portion of the eliminated glycerine, but not *all* of it. Red lead, however, *does absorb it all*, and it is for this reason that red lead is so reliable as a single-pigment water-proof coating for preventing corrosion under ordinary circumstances. Iron oxide, however, only partially absorbs the glycerine, though in a gallon of iron oxide paint there are more combined oxygen elements than in a gallon of red lead paint. It is the uncombined glycerine that is the prime cause of the unreliable character of a paint coating to resist moisture and consequent decay of both the coating and the body covered. Varnish menstruums, though carrying the same pigments as an oil paint, are more reliable coatings, for in them the glycerine has been eliminated in the process of manufacture. It is the presence of glycerine in a raw-oil paint that renders it possible to mix more or less water and soapy compounds with it as vehicles, and it is the function of a drier added to a paint, to combine with or mechanically absorb the glycerine, so that the union formed between the fatty acids of the oil and pigment shall harden and dry. All additions to a paint in the form of free or bung-hole driers lessen its stability, increase the chemical action that in a greater or less degree is present in all paints, and generally means the introduction of an acid element not at all necessary in the composition of any paint to render it protective or to harden it when spread.

60. The use of boiled oil as a vehicle simplifies the chain of

operations greatly in most paints, as it insures the absence of many substances injurious to the coating, other than those natural to the pigment. Of itself, it may not be as durable, either in the form of an oil-skin coating or a pigment coating in place, as compared with others from raw oil, that have time to dry *naturally*, without the use of driers (generally three weeks, and that is not always possible to allow), but there is no question of its superior quality as a menstruum as compared to the ordinary commercial raw oils (many of them should be classed as unguents instead of oils), loaded with driers, many of which are of the most unreliable character, and only induce in the drying oil a chain of mechanical functions, not chemical combinations, that ought to be confined to the boiling kettle.

Linseed Oil.

61. Linseed oil has a specific gravity of 0.928 to 0.953. The oil from an average sample of linseed extracted by various processes shows:

Hot Process.		Cold Process.		
Carbon 75.17%	100%.	Carbon 78%	100%.	The carbon disulphide process gives more oxygen and less carbon.
Hydrogen..10.98%		Hydrogen..11%		
Oxygen....13.85%		Oxygen....11%		

It corresponds to the formula: $\left\{\begin{matrix} C_{15}, H_{25}, O_2 \\ C_{32}, H_{54}, O_2 \end{matrix}\right\}$ Mulder.

It is anhydride of linoleic acid, $C_{16}H_{26}O_2$, an acid peculiar to all siccative or natural drying oils, and when fully oxidized by exposure to the air, forms oxylinoleic acid, $C_{16}H_{26}O_5$.

Hazura and Bower (*Monatschr.*, vol. 1, x., p. 459) found that the rate of oxidation and consequent hardening of this and other siccative oils depended on the ratio of linoleic and linolenic acids present.

Analysis of ripe linseed gives:

Albuminous Substances	24.44 per cent.	100 per cent.
Gum, Sugar, and Cellulose	34.00 per cent.	
Oil	30.73 per cent.	
Ash	3.33 per cent.	
Water	7.50 per cent.	

62. Unripe seed, or seed from flax raised for the fibre only (the condition from which most of the commercial oil is obtained), contains nearly 10 per cent. of water. The yield of oil from the different classes of linseed varies only from 23 to 28 per cent. of

the weight of the dry seed. Linseed yields in the process of extracting the oil, viz.:

Cold Process	about 20 per cent. of oil
Hot Process	" 27 per cent. of oil
Carbon Disulphide Process	" 33 per cent. of oil

or 15 to 18 pounds of oil per bushel of commercial seed, by the most improved processes of extraction.

63. Ireland, England, Belgium, and Central Europe raise the best flax for fabric purposes; the seeds gathered from these sources being unripe, furnish poor, thin, watery oil. Russia has the largest acreage in the world devoted to the raising of flax for seed purposes, and furnishes about one-sixth of the world's supply, the yield being about eight bushels of fifty-six pounds to the acre, the fibre being of minor importance, being woody and subject to great waste in the preparation of it for fabric purposes. Russian seed is exported to other countries for seed purposes as well as for its oil. Large quantities of hemp is sown in Russia with the flax, but as this furnishes a siccative oil its presence is not an improper adulteration, such as the seeds from the rape, mustard, colza and many other plants called "flax dodders," that furnish a *non-drying* oil. The adulteration from the seeds of these plants is so widely practised that the waste product of the oil mill in the form of oil-cake, formerly a valuable cattle-food product, is now so strongly impregnated with the biting taste of the mustard and other acrid substances that cattle refuse to eat it, and it is chiefly used for fuel or fertilizing purposes.

64. The American linseed, that furnishes 20 million gallons, about one-tenth the world's supply of linseed oil, is also strongly adulterated with mustard and other non-siccative oil seeds, that render the oil-cake almost valueless for a cattle food, besides contributing their quota of green, unripe seeds to the unripe linseed oil pool.

India furnishes about one-eighth of the world's supply of linseed. It is grown as a mixed crop for the seed only, the flax staple being of inferior quality and only 18 to 20 inches long. The climate appears to develop the oil-producing qualities of the seed, it yielding a larger amount of oil than seeds grown in a colder climate, though the colder the climate the better the oil. India seed is mixed with colza and rape-seed, both furnishing non-drying oils hard to separate from the linseed. Both are used for

lubricants, burning, and in the manufacture of india-rubber compounds.

65. The vegetable siccative oils of commercial importance are twenty in number, the principal of which are linseed, poppy, hemp, walnut, sunflower, grape, Scotch and silver fir, and spruce. The specific gravities of the whole number (20) range from 0.9202 to 0.9358, varying so little that the hydrometer test is of little moment to determine their character. The vegetable non-siccative oils of commercial importance are 76 in number, the principal ones being the castor (specific gravity, 0.964), olive, and cottonseed (specific gravity, 0.9306, almost identical with linseed), resin, almond, beechnut, horse chestnut, hazelnut, peanut, croton, sesame, colza, rape, mustard, with specific gravities ranging from 0.913 to 0.942. They mix thoroughly with each other as well as with the siccative oils, and the specific gravity of a pure linseed oil can be easily counterfeited, even if its quality cannot be. Vegetable oils additional to the above, used medicinally and for soap, burning, and food, are 85 in number.

66. Vegetable oils, volatile and essential, number 134, or a total of 293 non-drying oils available for the purpose of adulteration. Add 80 animal and fish oils to the above, and it may be conjectured the source from which a yearly supply from the whole world of 250 million gallons of linseed oil can supply a demand for about 400 million gallons of paints, varnish, japans, and other uses, including the wastes of manufacture.

67. If the flax is raised for the fibre, the seeds do not mature at the same time, hence they furnish a thin, watery oil with a greater quantity of the albuminous substances, gum, sugar, and cellulose, called "mucosities," than the 54.44 per cent. to 58.50 per cent. found in ripe seed. Unripe or mildewed linseed is no more capable of furnishing a good oil than a green apple will make either good cider or good vinegar; an unripe grape, good wine; or grain or corn harvested in the milk will make good bread; and no amount of juggling in the subsequent manipulations of the paint manufacturer can replace the simple operations of nature, or ripen her unripe products or produce them from synthetical compounds.

68. The composition and properties of the siccative oils have been but little studied since Mr. J. Nelson Neil was awarded the Isis Gold Medal of the Society of Arts in 1832 for a paper read before that society on "Oil Boiling and Varnish Making" (published in the *Transactions of the Society*, vol. xlix., part 2), which

treats so exhaustively upon the modes of manipulation, recipes, and precautions to be used, that the paper is the foundation for all subsequent accounts and modes of manufacturing varnishes. The additions and modifications which have been worked out since that time have not materially altered the processes of Mr. Neil, either in the betterment of the quality of the varnish or the oil product, but relate more particularly to a shorter time and possibly less cost of manufacture than given by Mr. Neil, which comprised the application of direct fire to the kettles instead of the steam-jacket kettles and devices used by later experimenters and manufacturers.

69. These experiments of Mr. Neil were followed by the experiments of Mr. M. E. Chevreul, who contributed a paper in 1856 to the *Annales de Chime*, corroborating Mr. Neil's deductions upon the drying of siccative oils, and by him clearly laid down, viz.:

First: That it is the absorption of oxygen by the siccative oils and the change of the oleic, margaric, and stearic acids of which they are composed, and the chemical combination with each other in the presence of oxygen into the linoleic and linolenic acids, that is the cause of their solidification, which term he thinks more clearly defines the action of the oil than drying, which in general may mean evaporation, which is a term adaptable to all liquid bodies, or rather indicates the removal of liquid from all bodies. This definition appears to be apropos to many of the latter-day cheap mixtures called paints; the difficulty experienced with some of which is not to have them dry in a reasonable time, but to have them keep liquid long enough to spread them at all.

Second: That the oxidation of the oil is a chemical process and naturally inherent in itself. The action of heat, as in boiling, hastens the drying or resinification of the oil by removing the water and mucosities. That all substances which can be used as driers must be such as are capable of parting with oxygen or dissolving in it; and being of themselves oxidizable in combination, they in that way increase its absorptive power. There is a class of driers (white copperas, for instance) which act while mechanically suspended or in contact with the oil, and increase its oxygen absorptive power by their presence, but leave no increase of drying power when withdrawn.

70. The substances that act catalytically part with some of their oxygen in the oil, and become to a certain extent deoxidized,

and again coming into contact with the air, either mechanically blown through the combined mass of oil and driers, or by surface exposure in the settling tank or barrel, recover their primal condition, and are ready to do the same work over again. It is the necessity for the reoxidation of the driers that causes the general adoption of the air agitation and steam processes now in general use for the boiling of oil and manufacture of varnishes, etc. These driers, without becoming in any way altered, induce an alteration in the linseed oil subjected to their operation. We may imagine this action as similar to that by which spongy platinum explodes a mixture of oxygen and hydrogen, or a platinum wire is kept red hot by the vapor of ether.

71. Prof. Chas. W. Vincent's experiments in 1859 were upon the line of boiling oil without the presence of driers, and that a high temperature was not necessary. The temperature used by Mr. Vincent was that due to steam at forty pounds per square inch, 267° Fahr., used in a steam-jacketed kettle in connection with mechanical agitation by revolving blades and a current of compressed air moderately heated by the act of compression. This process is that in general use at present in the manufacture of linoleum, and it is believed that the Germans practised this method many years preceding 1859. Professor Vincent's conclusions, drawn from experiment, were that air blown through the mass of heated oil *is not* as important a part of the process as many have assigned to it, and in reality effects nothing towards making the oil a drying one. He boiled linseed oil with air alone, *but without driers*, for three days consecutively, keeping up a high temperature the whole time, and the resultant boiled oil required precisely the same time to dry as the raw oil from which it was prepared. The body, however, had become so much increased that its consistency was more that of a varnish than an oil. In the oil subjected to the heat alone for the same time, without any air, except such as came to it in contact with its surface in the kettle, there was no such increase in its consistency as in the former case; the oil simply became more greasy, had less difficulty in penetrating the capillary tubes of paper, plaster, etc., than it previously had, and had decidedly *less* drying power. The oil that had been boiled with the air blast was less greasy and had a greater consistency. Briefly, the surface exposure to the air and the heat secured a sufficient amount of body. The driers produced any required shade of

color in the oil, and reduced the time of drying from three and four days, for the raw oil, to six hours in the summer and eight hours in the winter for the boiled. Boiled oil that is subject to long voyages at sea is apt to become fatty and not free working. This is due to the agitation it gets from the motion of the ship while it is under the increase of temperature due to the hold or cargo space in the ship, being, in fact, a long-continued low temperature and agitation process of boiling. The manufacturer guards against this result by adding to boiled oil for shipment by sea about one-fourth its volume of raw oil, the oil becoming brighter in consequence of the addition. Professor Vincent's steam kettle process of boiling gives an oil of a lighter shade than the direct fire or high temperature process. In both processes acrylic acid ($C_3H_4O_2$), a monobasic acid very soluble in water, is produced. It is oxidized from acrolein (C_3H_4O), the vapors of which escaping during the process of boiling are very irritating to inhale, and are highly corrosive to ferric bodies. Its presence is possibly due to the decomposition of the mucosities in the raw oil under the influence of the heat, and only indicates the slower decomposition of these substances in a raw-oil vehicle for a paint; the slower process of solidification of the raw oil enclosing them, as it were, in a film of the vehicle, to develop later into a destructive agent of the paint. The removal of these mucosities is absolutely necessary in the manufacture of linoleum, baking japans, and varnish; and if detrimental there, it must necessarily follow that they are equally so in a paint.

72. Professor Sacc's experiments in brief were 2,500 grains of oil boiled for 10 minutes only, with 30 grains each of litharge and red lead, and weighed after 24 hours' exposure to the atmosphere, the oil had lost only 60 grains. This sample increased 20 per cent. in weight after complete resinification. A second sample, boiled until there was a loss of 5 per cent. in weight of the oil, the product assumed a molasses consistency, and did not resinify after 15 days' exposure to the atmosphere. A third sample, boiled to a loss of 12 per cent., became a caoutchouc-like mass that the atmosphere had no effect upon whatever. It was insoluble in alcohol, ether, chloroform, and bisulphide of carbon: boiling naphtha only dissolved traces of it. The only action which dilute acids had upon it was to extract a small quantity of the oxide of lead due to the driers. In properly prepared varnishes and paints from pure linseed oil, the gain

in weight after thoroughly dry is from 8 to 10 per cent. of the vehicle, and it is heavier than water. Any paint that does not show a marked increase in weight in drying can be set down as having but very little siccative oil in its composition, and is one of the hundreds of bastard compounds that masquerade under the guise of paint, with more resin, fish and hydrocarbon substances in its vehicle than linseed or other siccative oils, and whose drying power or evaporation is principally expressed in the amount of benzine it can carry and still keep the pigments (good or poor) afloat.

73. The sulphuric acid process of boiling oil has been adopted with some modifications and additions by a number of manufacturers. It furnishes an oil of light color which, it is claimed, dries well and rapidly, and mixes with all pigments without leading to any discoloration; whites retain their purity of tone unchanged. But with all these points in its favor, the process cannot be recommended for the preparation of a vehicle to be used for a ferric protective coating. Briefly, the oil is first treated with a dilute sulphuric acid bath (containing about 30 per cent. of sulphuric acid), which is agitated with the oil by the air blast *to dehydrate it*, but is said to be not strong enough to carbonize it. After standing to allow the oil and acid to separate, the oil is run off into the usual steam-jacketed kettle heated to about 260 degrees Fahr., air is blown through the mass, while a solution of manganese linoleate in some hydrocarbon spirit (probably benzine) is added gradually during the process of heating and blowing. Cautionary care is required *not to add too much* of this material. It is the writer's opinion that this caution should extend to the point of not adding any manganese associated with any hydrocarbon vehicle to the oil, and that prohibition should extend to the use of any sulphuric, nitric, or other caustic acid of any strength to the oil in its preliminary stage. It is almost impossible to clear an oil of either high or low specific gravity, of any acid of whatever strength of solution to which it may be exposed. More or less of the clarifying acid will be held in the oil either free or in combination with the water in the oil, that even a long washing with water, aided by an air blast agitation, *will not remove*. Kerosene, naphtha, gasolene, etc., are purified by treating with sulphuric acid and then thoroughly washed with water and a long agitation by the air blast, and are then often found to contain acid enough to perforate the tin cases in

which they are shipped. The slight improvement in the color of the boiled oil by this process is a very poor recommendation for its use. The same results are obtainable by the ordinary steam kettle process, using well-known mineral substances; for instance, the zinc and manganese salts will remove or throw down the mucosities, clear the oil to any desired shade, and cause it to dry promptly, while the water in the oil will be evaporated naturally by the heat, and the dangers of the sulphur element avoided.

74. A series of interesting experiments upon the action of various mineral and metallic substances called "driers," upon boiled linseed oil, to determine the effect of the same on the color of the oil and time of drying alone, were made by Mr. Frank H. Thorp, S.B., published in the *Journal of Chemical Industry*, vol. ix., p. 628, also in the *Scientific American Supplement*, No. 757, vol. xxx., July 5, 1890. The details of the experiments are too long to include here, but the following results are probably as trustworthy as those noted by earlier experimenters. The oil experimented upon was in every case from the same barrel, and was a very light colored, cold-pressed Calcutta raw linseed oil, specific gravity 0.93—50 c.c. weighing 45.7 grammes. The several samples were treated in glass beakers arranged in a sand bath under temperatures from 200 degrees Fahr. to 300 degrees Fahr. In general, the temperatures from 230 degrees Fahr. to 275 degrees Fahr. gave the best results. The weight of oil under test was in each case the same, 45.7 grammes. The time of actual boiling was from 1½ to 2½ hours, and the percentages of driers varied from less than 1 per cent. to 2 per cent. by weight of the oil treated. Litharge furnished an almost colorless oil of firm film, drying in from 6 to 10 hours. Lead carbonate, lead acetate, lead borate, each furnished slightly colored oils with good films, drying in the order named, in 10, 12, and 20 hours. Red lead, lead chloride, lead tartrate, furnished dark colored oils of good films, drying in from 20 to 24 hours. Red lead and litharge, 2 per cent. of each, also the other lead salts mentioned, with larger percentages than two of each, gave dark colored oils, all with firm films, drying in about 24 hours.

75. Of the lead driers, litharge gave the best results both in color, film, and drying qualities. Care was necessary in the use of this drier to not overheat the oil, thus deepening its color. The zinc salts, the acetate, borate, citrate, oxide, and sulphate, furnished nearly colorless or slightly colored oils with fairly good

films, but their time of drying was from 36 to 46 hours. Larger amounts of these driers than 2 per cent. shortened the time of drying, and darkened the color of the oils, but they did not clarify satisfactorily.

76. The acetate and borate are the best of the zinc salt driers, but none of them act catalytically upon the oil as the lead and manganese driers do, but act mechanically or only while present (like white copperas), to throw down some of the mucosities, but do not cast them all out or set up the combination changes necessary to form the linoleic compounds required in a good drying oil. The manganese salts, viz., the acetate, borate, sulphate, oxalate, and tartrate, all gave colorless oils, drying with good firm films in from 20 to 36 and 40 hours. The citrate and formate gave slightly darker colored oils, drying in about 24 hours with good firm films. The manganese borate, with quantities varying from 1 to 3 per cent. of the oil and with temperatures of 220 degrees Fahr. to 230 degrees Fahr., gave the best colored and drying oils obtained in the whole line of experiments. The other manganese salts with larger than 1 per cent. of driers, with temperatures from 250 degrees Fahr. to 300 degrees Fahr., gave colored oils of unsatisfactory drying power, some of the samples being tarred. No definite conclusion can be drawn from Mr. Thorp's experiments as to the relation between the quantity of driers dissolved in the oil, and the time of drying of the oil. The action of the several classes of driers, as well as the various members of them, was erratic, and the drying result appeared to be governed quite as much by the temperature of the bath, time of boiling, and agitation of the oil during boiling, as by the chemical employed. One per cent. by weight of litharge and the lead driers, and two-tenths of 1 per cent. of the manganese salts, were all that were required to give good bright colored oils of good drying qualities with firm films, and not all of these amounts of driers were taken up by the oil, but some was recovered in the residuum.

77. Of the many substitutes for linseed oil neither space nor patience can be given to note them. They are numbered by the hundreds in the Patent Office records, and outside in the formulas of the many paint compounders of the day, and are as uncertain and indefinite in character as the pigments which are assembled with them under the guise of paints. Linseed or other siccative oils of low commercial qualities, and in small quantities, are mixed

with one or more of the score of flax dodders or buffums, resin, fish, burning, and soap-fat oils, india rubber, and other impure substances, liberally dashed with benzine of high or low degree and braced up with a bung-hole boil of umber or other cheap driers, and then presented to the supply agent and public as pure linseed oil at a price below the regular market quotations of linseed oil from responsible business firms. The purchasing agent, as well as most of the master painters (except in a few cases), have not the laboratory, chemical apparatus, or technical knowledge to detect the fraud; the results only being made patent by the slow gnawing of the tooth of time, and at a period when it is too late to remedy except by the scraper, burning torch, and a new coating that may or may not be better than the one that it replaces.

78. Probably 70 per cent. of all the oils, paints, and varnishes manufactured in the world is applied to structures of minor importance, and which are destroyed in the course of time by other causes than corrosion. The coating of these structures is generally more a question of looks than physical condition, but the other 30 per cent. is used upon the largest, most costly, and important engineering structures created by man, urged on by the strong spur of competition, honor, and hope of gain. These require suitable protection from corrosion from the very hour the materials leave the rolling mill, foundry, or forge until they are in the finished structure, and need more then than during construction. The most casual inspection of the ferric structures that line our railways and are counted by hundreds in the various cities of the country will show that they have not thus far received the intelligent treatment their importance or life demands.

Decay of Paint.

79. A coating of paint may appear to be a very simple thing, as it is when applied to a house or barn and both left to their fate; but when applied to an important engineering structure, with all the vicissitudes of service in the extremes of heat and cold, sunshine and storm, atmospheric and other gases from natural or manufacturing sources, from corrosive liquids and solids, it is a different matter, and requires more engineering skill to devise it, more chemical knowledge to compound, and technical details to get the right thing in the right place at the right time in the right manner and in the right amount, than the general run of master painters can or do give to the subject. If the influences

to which a coating of paint is to be subjected are known, it can generally be determined in advance whether it will be durable. For instance, zinc white or oxide (ZnO, specific gravity, 5.42) applied as an external coating absorbs carbonic acid from the air and some moisture, changing to a carbonate of zinc ($ZnCO_3$, specific gravity, 4.44). During this change there is an increase in volume from 14.9, as an oxide, to 28.1 as a carbonate. This change from an oxide to a carbonate is a chemical one and occurs during the process of drying, but the *change in the volume* of the two substances exerts a mechanical action also in the atoms of the pigment to not only disrupt them and leave them loose and easily carried away by the wind, rain, etc., but cracks and loosens the oil menstruum in which the pigment is embodied, as well as its bond to whatever surface over which it is spread. But if the zinc oxide coating is applied in a closed room, though the air contains the same amount of carbonic acid, or even more than the external air, the oxide does not change to a carbonate, as the necessary moisture is lacking, hence zinc oxide for internal coatings is durable, but for outside coatings is perishable.

80. Red lead (Pb_3O_4, specific gravity, 9.07) remains unchanged under ordinary atmospheric conditions, but if the air contains hydric sulphide, as it does in many manufacturing establishments and towns, to a notable extent it will, by inexorable chemical laws, change the oxide to a sulphide of lead (PbS, specific gravity, 7.13), and this chemical change (usually denoted by the blackening or discoloration of the coat) will also be accompanied by an increase in volume of the sulphide of about 33 per cent., this increase acting mechanically to disturb the bond between the pigment menstruum and surface coated.

81. The addition of carbonate of lime (chalk) to an iron oxide pigment, whether made from the natural iron ore, or from calcined copperas ($FeSO_4 7H_2O$), to neutralize the sulphuric acid developed in the calcination of the copperas or roasting of the natural ore (as heretofore noted), is another instance in which an inexorable chemical change in one of the pigment's loose substances is accompanied by a change in its specific gravity, its corresponding change in volume, and a mechanical action to reinforce the chemical action due to the raw oil vehicle loaded with its charge of driers, whose function is to either decompose or consume by a slow combustion the mucosities in the oil while attempting to dry. All these instances are similar in effect to what

would occur in the plastered wall of a building if the mortar used in it, when partially dry, should begin to increase in volume to the amounts as given above. Other instances could be cited, but these show that the pigments of the coating can be so chosen as to preclude the destruction by them of the coating, but that it is almost impossible to guard the menstruum from the injurious influences inherent in the composition of the pigment, that is changed in character after its application by inexorable chemical laws. Hence the absolute necessity that an order for a protective paint should include the conditions it is to be subjected to in use.

82. In addition to the preceding remarks upon iron oxide, graphite, and other paints, and the several tests given in detail of a few of the many paint compounds of the day, it may be noted, viz.: All pigments can be grouped into three classes according to their affinity for linseed oil.

First. Those that form chemical combinations called soaps and are generally the most durable. They consist of lead, zinc, and iron bases, of which red lead combines with the oil to the greatest extent; next, the pure carbonate white lead made by the Dutch process, followed by zinc oxide and iron oxide, turkey umber, yellow ochre; also, faintly, the chromates of lead, chrome green, and chrome yellow.

Second. Pigments of this class, being neutral, have no chemical affinity for the oil; they need large amounts of driers, either combined with and carried by the oil, or as free driers. They include all blacks, graphites, slates, slags, vermilions, Prussian, Paris, and Chinese blues, terra de Sienna, Vandyke brown, Paris green, verdigris, ultramarine, carmine, and madder lakes. The last seven are transparent colors, and are better adapted for varnish mixtures and glazing.

Third. Pigments of this class act destructively to linseed oil. They have an acid base (mostly tin salt, hydrochloride of tin and red wood dye) which forms, with the albuminous and gelatinous matters in the oil, a jelly-like compound that does not work well under the brush nor harden sufficiently, and can be used in a varnish for glazing only. Among the most troublesome are the lower grades of so-called carmines, madder lakes, rose pinks, etc., which contain more or less acidulous dyes, forming with linseed oil a soft paint, that dries on the surface only and can be peeled off like the skin of a ripe peach.

83. Catalysis, a term introduced by Berzelius, and by him ap-

plied to the changes that sugar solutions undergo in the process of fermentation, is now used to denote the changes that certain substances by their mere presence effect in other bodies without themselves undergoing any apparent change. Catalytic action is a potential agent in the decay of paint coatings, and manifestly has not received the attention from paint chemists and compounders that its marked action on the life of a coating warrants. The present efficiency of the incandescent gaslight is wholly due to catalytic action between the substances that compose the mantle when excited by the combustion of the gas. In the development of this light all of the rare mineral oxides and metals and the oxides of the baser metals, chromium, alumina, cobalt, manganese, nickel, and iron, when associated with thoria in the mantle, have been found to act as catalytic agents to carry, condense, or absorb oxygen, that increases the flame temperature of the mantle and consequently increases the light. This flame temperature in some cases reaches the point where volatilization of some of the baser metals and oxides ensues. Charcoal, powdered glass, porcelain, fluor spar, crystallized quartz, pumice stone, and other kindred substances are also found to act as catalytic agents in combustion, but do not develop so high a flame temperature in the mantle as the other substances above noted.

84. Combustion of any substance may be quick and attended by a high temperature, as in the case of the incandescent gaslight, or it may be of low temperature and extend over years of time, but the amount of heat evolved from the destruction of the substance, and the resultant products of combustion, or decomposition, are the same in all cases, even if the physical effects are apparently different.

85. Nearly every substance in a paint coating has been found to be catalytic to some other substance, either in its own class as a so-called inert mineral pigment, or in the chemical class of oxides having a lead, zinc, iron, or other metallic base. Individually, they may be apparently unaffected by long exposure to the air while in their loose state or in packages or bulk; but when mixed together, they take up moisture or oxygen to a greater or less degree, either by absorption in mass or by condensation upon their surfaces, and catalytic action ensues. The oil menstruum and driers are catalytic of themselves, and when mixed with the pigments act more energetically as carriers of oxygen even when the coating is apparently dry. In all pigments and menstruums, the one that is the most re-

fractory, or that is the most resistant to oxidation in whatever form the oxygen may be presented, is the one that acts the part of the thoria in the gaslight mantle, becoming the negative or non-consumable substance that, though excited to a greater activity by the presence of the other substances in the paint compound, retains its resistance to a change the longest at the expense of the other associated substances. Thus far, lampblack and graphite, in their subdivided form as pigments, appear to be the only substances not subject to catalytic action, or if it is present it is so weak that the life of the coating is not materially affected from this cause.

Painting at the Mill.

86. Many engineers are advocating the plan of having a coating of protecting compound applied to iron or steel at the rolling mill as soon as possible after it has left the rolls or hammer, and while the material is hot. The *hot* part of this plan is the only part to commend. All material from the forge or rolling mill has a tough, thick or thin (as the case may be) coat of loose or partly loose scale, that adheres closely for the time being, but on a short exposure to the air with a few changes of temperature, due to the mill or storehouse conditions, releases its tension and is ready to fall off whenever roughly handled, as in the course of loading and transportation. No amount of brushing which any rolling-mill employee would or could give to the material in its hot or half-cold condition would remove this scale, and if the painter were present with his pot of paint, it would get on over scales and all, and no inspector could prevent it. The quality of this paint, even if rightly applied, would always be in question, and no contractor could be in any way sure that the contract requirements had been complied with, either in the removal of the scale or the composition of the paint. All the machining operations are accompanied by more or less lubrication of the tool, and the oil used is invariably the cheapest to be had for that purpose, and has in general been used over and over again, is dirty and sour, and more or less decomposed, and carries enough hydrocarbon elements to evaporate to a dirty surface skin, hard to distinguish from the coating applied at the mill, the sequence being that the inspector, if careless in the discharge of his duty and anxious to get the work out of the shop, and to show a large day's work, does not notice the grease or other dirt due to the machining process which is not removed, but coated over by the

ever ready painter, anxious to show his great day's labor, and, as a class, notorious for scrimping everything which calls for manual effort, and jealous of any attempt to confine him to a procedure at variance with what he thinks is a special function of his own craft. Rather let the material go from the mill or forge to the storehouse or construction shop, protected as far as possible from any unnecessary exposure to the elements, and when machined, during which process the greater part of the scale will be removed, and when the several parts are assembled in their relative positions and ready to be riveted up into their permanent places in the structure—if it is done at the shop instead of *in situ, then and there* is the place for the inspector to determine if the several parts are not only properly machined, and also properly cleaned from the scale which has not been removed by the machining process and handling, but that the grease and dirt are also removed *in his presence*, and the first coat of the paint is applied under his eye in a manner, as to the conditions of temperature, frost, fog, wet or dry, and *quality of paint*, which will insure a proper protective result. Nothing can serve as a cloak to hide *his own responsibility* in the matter. One inspector and inspection at the last and final stage is better than two or more inspectors and inspections strung along over a chain of operations comprising months of time and often hundreds of miles between the links.

87. What results, other than a prompt corrosion, could follow where an engineer, on his examination of construction work in progress for his own firm, reports: "The removal of the rust spots and mill-scale was being done by *putty knives and whisk brooms*. Steel brushes were also used. [Evidently as a minor appendage to the broom.] If there was *anything unusual* in this method of cleaning at the shops, *it was on the side of thoroughness*. After cleaning, the plates *still showed thin yellow rust spots*, and these showed plainly but of a darker color after the oil coating was applied." (The italics are the writer's.)

88. Every atom of the rust or mill-scale thus left in place and coated was electro-negative to the coated surface, and ready to commence the process of corrosion whenever moisture from any source reached it. The thin film of oil, from $\frac{1}{1000}$ to $\frac{1}{500}$ inch thick, would not delay corrosion much longer than the time required to dry. If the oil was of the bung-hole boiled variety, containing 7 to 10 per cent. of water, corrosion would start the more promptly.

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DISCUSSION.

*Mr. George E. Long.**—The fact that Mr. Wood has referred to the use of various graphites as substitutes for Siberian graphite, and also his remark as to the use of foliated graphite in the manufacture of pencils, would indicate that his knowledge concerning the various supplies and uses of graphite is not entirely complete.

We note a number of statements which are not in accordance with theory or with practice.

Calling attention first to his remark in paragraph 25, we must object to a statement concerning the mixture of flake graphite with such other substitutes as barytes, silica, and furnace slag. Mixtures of ordinary crystalline graphite other than in its laminated or flake form are common, but where a company mines and prepares for its paint pigment a natural product, it need not make use of any slag or barytes or any other ingredients of

* By invitation.

that sort. The product is merely pulverized to the fine condition necessary for a paint pigment, so that in this particular the two pigments are identical. Even if such admixture had been made, Mr. Wood has failed to say in his paper that any such admixture would be more injurious than the natural earthy components which are a natural ingredient of the Superior paint pigment.

In paragraph 26, Mr. Wood refers to the heterogeneous character of flake graphite pigments. We need say nothing more on this point than to compare the statements we have just made with a reference from the *Engineering and Mining Journal*, January 1, 1898: "There was produced in Baraga County, Mich., 100 tons in 1896, and 600 tons in 1897, of a carbonaceous material, which is ground for paint and is improperly called graphite. It is simply a carbonaceous schist extending over several thousands of acres, without sign of any vein of graphite. The quarry is situated in Sec. 33, T. 50 N. R. 33, W."

Mr. Wood's statement that graphite is hard to grind other than in a flake form does not come near enough to the truth. He should have said that it is impossible to grind it other than in the flake form. If we considered other forms of graphite suitable for a paint pigment, we certainly would not go to the expense of grinding the Ticonderoga flake graphite to the fine state of division necessary for a paint pigment. Other forms are very much easier to pulverize.

Mr. Wood also speaks of the granular form as being an ideal form for a pigment particle. Mr. Wood has not demonstrated this, and on this point we propose to take issue with him. It is the point really under discussion. He has made certain statements with regard to the position which the various particles assume in the paint skin. In reading his paper, one might assume that great care was exercised in placing these cubical particles he refers to, much as paving blocks are laid on our streets. We do not think the ordinary painter goes to this trouble, but we do know that if a cartload of Belgian blocks are dumped out in the street, they would be distributed very irregularly, and that the voids would be almost as great in volume as the space occupied by the stones themselves, and we think it entirely fair to assume that this is the approximate position which granular and cubical particles would assume in a paint pigment. On the other hand, if the cart contained pieces of

thin slate which were dumped on the street, they would be found spreading over a very much greater area, and with the pieces of slate lying approximately parallel. We think that this is a fair illustration of the difference between a granular paint pigment and a flake pigment.

When we consider that the life of a paint depends upon the life of the oil, we see at once why the flake graphite is so very suitable as a pigment. The ideal pigment would be such a one as would entirely protect the oil from all exterior contact. If we could imagine a very large plate of graphite, say a yard square, firmly attached to some metal surface by means of a film of linseed oil, we will have an ideal condition; such a surface would probably last indefinitely. The use of flake graphite as a pigment allows us to approach this very closely. The thin flakes of graphite lying close together, separated, and attached only by an extremely thin film of oil, allow only the edge of the oil to be acted upon by destructive influences. On the contrary, when a granular pigment is used, the percentage of oil exposed must necessarily be greater than that of the pigment. The thickness of the paint skin is dependent upon the thickness of the pigment particles; thus if we assume the pigment as having a least dimension of $\frac{1}{100}$ inch, we cannot have a paint film of any thickness less than that, and the oil fills up all of the space between the particles and pigment.

When flake graphite is used, the flakes lying flat, we are able to get a very much thinner paint skin. This explains the great spreading capacity of flake graphite paints, as compared with other forms of pigment.

Referring to the statement that flake graphite is oil repellent, we need only to state the fact that one part linseed oil will coat 99 parts of graphite so that, when squeezed in the hand, a finely coherent mass is obtained. The idea that graphite is oil repellent is not warranted by the facts.

Mr. Wood, in paragraph 31, makes reference to certain laboratory tests. Laboratory tests are never conclusive, and these tests in particular were in no sense parallel to the ordinary conditions which paints are called upon to withstand in actual service.

We note several other statements which are not in agreement with the facts, such as difficulty of spreading flake graphite out, and that the graphite tends to separate from the siliceous portions of the paint.

Mr. Geo. N. Comly.—The Solvay Process Company manufacture a paint which they call Crysolite paint, which they have found to be of great service in painting iron work that is subject to corrosive action from ammoniacal gases or liquors, or other chemicals of that sort.

I do not think I can do better than to read a portion of an article written by their chief chemist, John D. Pennock:

"The rusting or corroding of iron surfaces is due to the action of (1) moisture, (2) oxygen, and (3) carbonic acid. To prevent the attack of these gases and the consequent rapid destruction of the iron, coatings of paint of many kinds are used. The efficiency of these paints to completely cover and keep out these gases is by no means alike in all cases. Some coatings even increase rather than diminish the corrosion; some forming a more or less porous coating, only prevent, partly, the corrosion, and others exclude almost completely the destructive gases, but are themselves destroyed in a very short time, scaling off and leaving the surface of the metal bare. The paints commonly used for coating iron surfaces, such as cast and wrought-iron pipe, bridges, corrugated iron, etc., are:

"(1) Iron oxide paint.

"(2) Red lead and linseed oil.

"(3) Varnishes with asphalt as base.

"(4) Carbon paints.

"An iron oxide paint on iron is the worst possible coating to use. It not only does not protect the metallic surface from the destructive influence of the elements, but, being oxide of iron, or rust itself, it acts as a carrier of oxygen to the fresh, clean surface of iron beneath the paint. Combined with linseed oil the results are no better, for the oxide of iron acts as an oxidizing agent towards organic matter, thus destroying it, and itself being reduced to a lower oxide. In the state of lower oxide it soon takes up more oxygen, and the process of carrying oxygen to the iron continues and the destruction of iron goes on.

"Red lead paint is a mixture of the red oxide of lead and linseed oil. The same oxidation of the metallic surface under the coating goes on, as is the case of iron oxide, though less rapidly. Linseed oil, according to the most eminent authorities, when dry does not act as an impervious coating to moisture, and is but as a sponge. This is certainly the case unless the linseed oil

forms a chemical combination with the pigment, which, I believe, is not the case with red lead.

"Varnishes, with asphalt as a base, do not stand the action of moisture, particularly if there are chlorides present, as is frequently the case in certain soils. Asphalt paints blister badly and peel off. The gums of which the asphalt varnishes are made, deteriorate, become brittle and crack off, leaving the metal exposed.

"The requisites for a good paint to prevent the rusting of iron and steel surfaces are that the paint shall form, in one coat, a perfectly uniform coating, non-porous, and impervious to moisture, air, and carbonic acid gas; that the coating shall be lasting and durable, and not deteriorate with age; that it must not be greatly affected by change of temperature; that it must be sufficiently hard to resist abrasion, and yet sufficiently elastic to adapt itself to the come and go of the metal during expansion and contraction. Of course the paint should be such as can have no chemical effect which is detrimental to the iron surface which it covers.

"The paint most completely fulfilling these requisites is a pure carbon paint. It is universally admitted to be unchanging in character, and when mixed with a suitable vehicle or carrier, produces a paint which cannot be surpassed for protecting iron and steel from rust.

"The Solvay Process Company, of Syracuse, N. Y., are manufacturing a pure carbon paint bearing the name of 'Crysolite.' It has been very carefully tested about their extensive plants at Syracuse, N. Y.; Detroit, Mich.; Dunbar, Pa.; Ensley, Ala.; Sharon, Pa., and Wheeling, W. Va., and has been found superior to any of the many paints they had previously tried.

"It is understood that the paint is made from a by-product resulting from their numerous coke operations.

"The tar produced from the by-product coke ovens differs from gas-house tar in many respects. The pitch resulting from the distillation of the tar contains a large percentage of free carbon, and this pitch, after proper purification, is the base of 'Crysolite' paint.

"The prejudice against tar paints arises from the fact, in most cases, that tar itself, without any purification, is used as a paint. Tar contains many substances, carbolic acid, ammonia salts, carbon bisulphide, etc., which are volatile and constantly changing

in composition, thus breaking up the coating of paint, and, besides, are injurious themselves to iron surfaces.

"By proper treatment during distillation, the by-product coke-oven tar produces a pitch which is free from injurious ingredients.

"In the case of 'Crysolite' paint, the purest possible form of carbon, purified hard pitch from by-product coke-oven tar is used, and for a carrier an oil of such consistency, and of such boiling point, that the paint will dry within the usual time and form a smooth, perfectly impervious, elastic, durable coating.

"For many years the Solvay Process Company had been endeavoring to find a paint which would withstand the action of the many chemicals which come in contact with the coatings upon iron surfaces exposed to the elements, and on apparatus inside of the buildings. Many kinds of paints were tested and all proved to be inefficient.

"One test to which 'Crysolite' paint was put, was the painting of a corrugated iron passage-way, exposed on the exterior to lime dust, ammonia and carbonic acid gas. To compare with this paint a portion of this passage-way was painted with graphite paint; another portion with asphalt paint. After the expiration of six months the asphalt and graphite paint were both in bad condition and iron rust appeared, whereas that portion of the passage-way painted with 'Crysolite' paint was still intact, and had a bright, glossy surface.

"They likewise find that this 'Crysolite' paint, when used upon ammonia tank cars and large ammonia liquor reservoirs, stands the action of the ammonia liquors and gases much better than any other paint they have used.

"As a further test of the durability of this coating, they painted wrought-iron tubes, three inches in diameter, and exposed them, after a baking process, to the action of carbonate of ammonia and ammonium chloride liquors for three months, and when these pipes were removed they were found to be in perfect condition.

"O. H. Tappan, Superintendent of the Hannawa Falls Water Power Company, Potsdam, N. Y., in a recent letter said, concerning 'Crysolite': 'The paint seems to be all that is desired. I tried it with a sledge on a very cold day last week, and it would not fly off, in spite of the sharp blows near the edge of a section of the penstock.'

"As a material for coating metal which is to be subjected to the action of sea water, there is nothing that will stand so well as 'Crysolite.' Sheet-iron plates 6 inches by 3 inches, painted with 15 different varieties of black paint for coating iron surfaces, were exposed for two months in sea water. Among these paints were black varnishes, asphaltum, graphite, and other kinds. At the end of the two months the sheets painted with 'Crysolite' showed no tendency to rust whatever, and the coating was in a hard, tough, and elastic condition, while all the others showed more or less rust spots; or the coating had blistered and peeled, particularly was this so with the varnish coatings; or they had become brittle and cracked off. Similarly painted sheets were suspended over a railroad track where passed 20 trains per day, for three months, so that they got the effect of the exhaust from the locomotive stacks. The 'Crysolite' paint stood this test equally well."

The question of painting iron work around chemical establishments is quite an important problem, and the ordinary paints have proved not to be successful for the purpose; and this that I have read is the outcome of experiments in order to find something which would successfully answer the purpose.

Prof. Dugald C. Jackson.—I am not a paint expert, but in paragraph 44 of this paper is to be found a statement which has proved of interest to me, and it is along the line of a considerable series of experiments that we have carried out in our electrical engineering laboratories. The statement which I refer to is to the effect that in bridge members and similar pieces of metal, where they have been worked, the metal seems to be easily affected by corrosion—this corrosion being properly characterized by the author of the paper as caused by electrolysis. It is a curious fact that the most accepted records, as they now stand in engineering literature, apparently show by the results of experiments, that the unstrained metal should be eaten away in such cases and the strained metal left intact, while the practical fact is the opposite—that is, the strained metal is really eaten away and the unstrained is not.

In carrying out an extended series of experiments in respect to the corrosion of iron, which covered several years of time, we have found that, where a piece of wrought iron or steel is placed in a testing machine and its electrical condition is followed up, as the iron—if it is iron, or steel, if it is steel—is strained, its

corrodibility appears to increase practically in proportion with the strain, above the elastic limit, so that a diagram plotted with stress along one coördinate and corrodibility along the other, appears to be of almost exactly similar character to a diagram plotted with stress and strain along the two axes of coördinates.

Two illustrations of these diagrams are presented in Figs. 303 and 304. The test pieces used in the experiments from which the results illustrated in the figure are derived were of wrought iron.

This demonstration, that in certain metals the corrodibility depends on the condition of the strain of the metal, is one of the important facts brought out in our investigation to which I have just referred. A report of the portion of the investigation which contains the experiments on strained metals is published in the *Bulletin* of the University of Wisconsin, No. 42.* The results to which I have referred are directly opposed to the generally accepted view which is based on the Andrew's experiments.† On the other hand, they give a perfectly satisfactory explanation of much of the so-called grooving in boilers and corrosion of a similar character. Here the strained metal of a punched boiler plate that is not completely covered by a rivet head becomes eaten away. Or perhaps a plate becomes strained at a joint by temperature stresses and the strained streak is corroded. In each case *the strained metal is of greater corrodibility*, and it acts as one of the plates of an electric battery in which the other plate of the battery is the unstrained metal of the boiler shell, and the electrolyte is the water within the boiler. The strained metal is the electrode which corresponds to the zinc of the ordinary voltaic cell, and it is eaten away.

Another illustration of corrosion of this character is the so-called (by bridge engineers) Cooper's lines, which are often evidenced in the corrosion of bridge members such as is referred to in paragraph 44 of the paper. These are lines of electrolytic corrosion in strained parts. The most seriously strained parts, or parts that have become hardened in working, become eaten away by voltaic action which goes on at their expense, and the less strained parts are less rapidly corroded, thus leaving the appearance of lines of corrosion.

* "An Experimental Study of the Corrosion of Iron under Different Conditions," by Carl Hambuechen.

† *Trans.* Institution of Civil Engineers (London), vol. cxviii., p. 356.

It is also true that metals which do not change their physical characteristics when strained, apparently do not materially change in corrodibility as the result of strain. Thus if one stretches lead, its corrodibility does not appreciably increase. The same is true to a certain degree of brass and copper. Fig. 305 represents a stress-corrodibility diagram for hard-drawn copper. The same is true also, to a limited degree, of very soft iron, but as even the softest iron does harden (that is, change in physical characteristics) somewhat when strained, its corrodibility is somewhat affected by strain.

Hein, in some experiments made years ago, found that he could make a fair determination of the mechanical equivalent of heat by measuring the heat produced by a blow of given energy delivered upon a lead or copper block. If he had tried iron he might have found his results entirely at variance with the facts, because much of the energy of the blow on iron (if it is strained beyond its elastic limit) is absorbed in the physical changes of the metal, and does not appear as sensible heat. Dr. Carl Barus, who is now a professor at Brown University, made experiments some years ago, in which he found that as much as one-half of the energy exerted in stretching an iron wire to the breaking point goes into the physical changes of the metal, the remaining part of the energy goes into sensible heat and raises the temperature of the test piece. The energy which is stored in the metal by the physical changes increases its chemical activity, and therefore increases its corrodibility as compared with the unstrained metal of the same kind. If experiments like those performed by Dr. Barus were repeated with lead wire, it would probably be found that all or nearly all of the energy exerted in stretching the lead wire to the breaking point is converted into sensible heat, and that little or none is absorbed in physical changes with their resulting alteration of chemical character.

The case of cast iron is interesting. Fig. 306 shows the stress-corrodibility diagrams for two specimens of cast iron in tension. A comparison of these diagrams with those for wrought iron in tension, illustrated in Figs. 303 and 304, shows the marked difference between the two metals. Fig. 307 shows a stress-corrodibility diagram for cast iron in compression. The exact forms of the diagrams taken from cast iron depend in some degree on the physical character of the specimens, but the diagrams shown

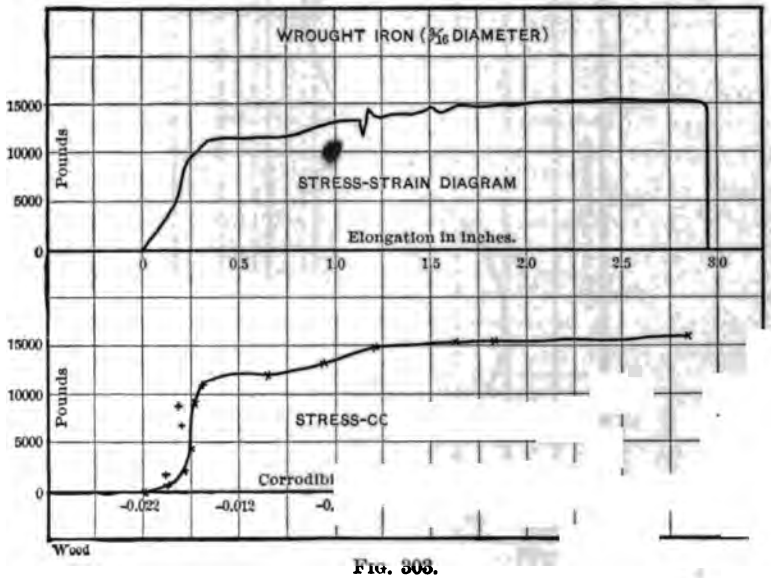

FIG. 303.

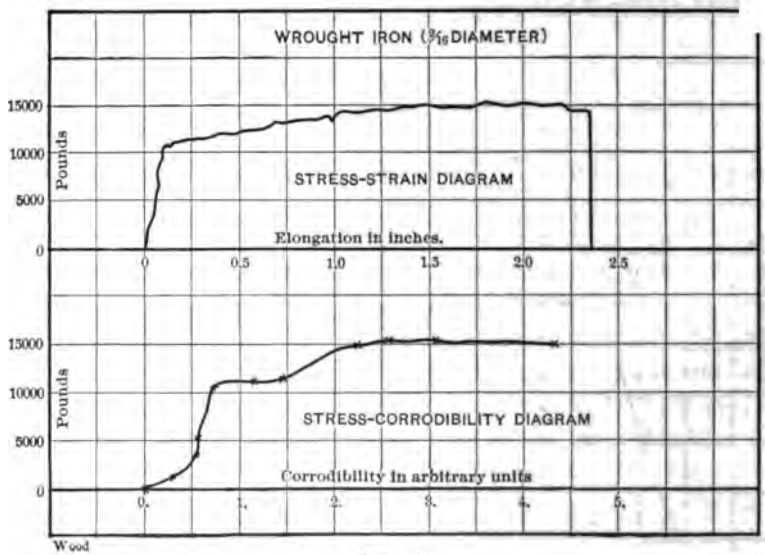

FIG. 304.

COMPARISON OF STRESS-STRAIN AND STRESS-CORRODIBILITY DIAGRAMS, WROUGHT IRON.

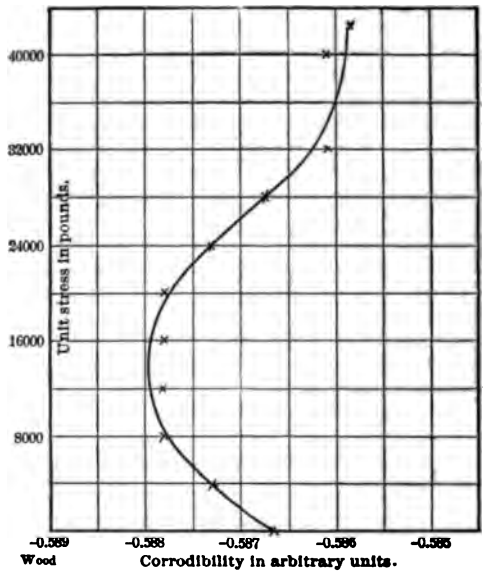

FIG. 305.—STRESS-CORRODIBILITY DIAGRAM OF HARD-DRAWN COPPER WIRE.

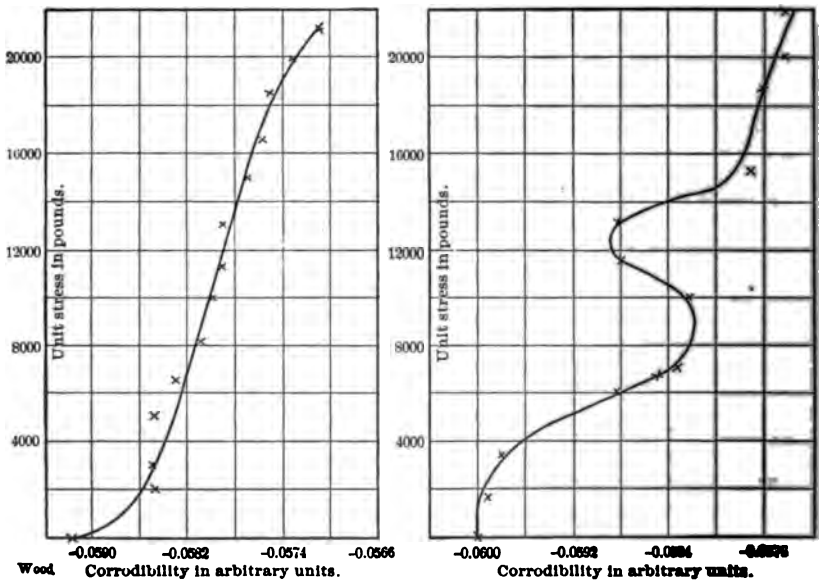

FIG. 306.—STRESS-CORRODIBILITY DIAGRAMS FOR CAST IRON.

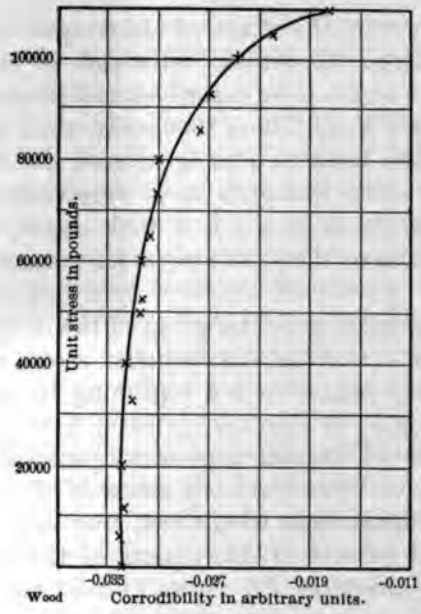

FIG. 307.—STRESS-CORRODIBILITY DIAGRAM OF CAST IRON IN COMPRESSION.

are typical ones. The effect of strain is small in the case of cast iron.

The corrodibility of the specimens, which is illustrated in these various diagrams, was measured by determining the electromotive forces of the test pieces toward a standard electrode in a normal solution.

*Mr. M. P. Wood.**—The influence of stress or distortions in metal for promoting corrosion, in paragraph 44, referred to by Professor Jackson, in which he endorses the writer's views in contravention to the generally accepted engineering opinions on the subject, and which have been referred to before in the *Transactions* of this Society, vol. xvi., paper No. 626, pp. 370–373, is furthermore corroborated by reference to the corrosion of a sample test bar broken under strain, illustrated and described in *Transactions* of this Society, vol. xv., paper No. 598, pp. 1035–1036, where the development of corrosion in proportion to the amount of strain was very marked, as will be seen by consulting the reference given.

* Author's closure, under the Rules.

Another example of the effect of electrolysis in metal under strain is given in the calamitous destruction of the Peoria (Illinois) water-works stand pipe, described and illustrated in *Engineering News* (New York, June, 1900). In this case the effects of corrosion in the form of pitting around the rivets and the furrowing of the seams (Cooper's lines) were very marked at the points of greatest stress in the iron tank sheets, and were the cause of the collapse of the structure under normal conditions of service.

Many other instances could be given of the dangerous character of electrolytic action on metals under stress, and it is only recently that many engineers are beginning to consider its importance.

The commission of English engineers appointed by the English Government to investigate the cause of the failure of the Tay Bridge, reported that, where cast iron and wrought iron were connected by rivets in many parts of the same structure (as they were in this one), the rivets and connecting wrought-iron work where connected to the cast-iron members of the structure (columns, flanges, spandrels, etc.), had corroded to such an extent as to be below the point of stability by the local galvanic circles formed at numerous points in the structure where the two metals were in contact.

The corrosive action noticed in the riveted sections of the tubular bridge over the St. Lawrence River at Montreal, Canada, referred to before in this paper, was of a similar nature to the above water tank example. In this case, while the corrosion was of almost unparalleled amount and virility in the whole structure, the rivets that held the floor beams and track stringers in place, and were under the greatest strain and subject to vibration and shock from the passing of the railway trains, were corroded the most, though all of these parts were of wrought iron to wrought iron, but varied in quality from common iron to refined iron.

A paint composed of the oxides of iron, lead, and tin pigments mixed with the best of oil, when spread and dry, will develop under atmospheric conditions a galvanic action from the presence of the metals in contact, and will deposit the tin in the form of metallic flakes which can be rubbed off and out of the coating by the fingers. The corrosive action upon the covered ferric surface follows as a sequence. If any zinc oxide is present

the galvanic action is more marked, the zinc being the first destroyed, then the tin, next the lead, while the iron pigment attacks the iron surface as usual.

Mr. Comly's contributed article on "Crysolite" is of interest, but it is regrettable that its value was not enhanced by a description of the particular kind of graphite paint with which the "Crysolite" was in competition, as per page 815. There are a dozen or more so-called graphite paints in the market, with almost as many points of contested excellence, and it would be of quite as much interest to place upon record for the benefit of the craft *what not to* use under certain circumstances as what to apply.

"Crysolite," as a mineral pigment, is of no more value in a paint than silica, barytes, or any other mineral substance which, of itself, is unfit for a paint, and as an added substance or adulterant could only be used to eke out some deficiency in the basic metallic pigment employed, or to mask some other adulterant for a change in color, or other misleading characteristic not required in any make of honest goods.

"Crysolite," as a trade mark, is as catchy as "Asbestos," "Bessemer," "Scale Armor," "Electric," and the many other names which come and go, while corrosion, the great enemy of ferric bodies, lives on forever. In the absence of any description of the manufacture of "Crysolite" other than that it is a product from a coke-oven coal tar, we can only assume that in its general characteristics it is like all other coal tars, the name coal tar being a generic term applied to those bitumens extracted from bituminous coal by the various processes in the manufacture of fuel or illuminating gas and hard or soft coke, and which vary in character according to the kind of coal used, the amount of richer cannel coal or other enriching substances used with the coal, the process of manufacturing gas employed, and to numerous other details not necessary to mention.

That the tar from a by-product coke oven is different in composition from that made by a gas retort is possible within a limited degree, as there is no known method of accurately showing the true condition of coal tars, no two tars being identical in every respect, although many tars are identical in every essential respect. The tars vary in the amount of bitumen they contain, from 60 to 92 per cent., and the processes of distillation to free them from their many acids, salts, sulphides, etc., vary in

temperature from 200 degrees to 600 degrees Fahr. The character of the residue, cement, bitumen, or whatever it be called, depends upon the distillation processes employed, even when dealing with a given tar; and again, the process will vary the character of the residue in proportion to the amount and quality of the oil the tar contains. The quantity of oil removed from a tar at any given temperature varies greatly. One per cent. of oil taken from one tar will produce a greater hardening effect on the residue than 1½ per cent. will upon another. Mechanical agitation, or blowing air or steam through the still, also affects the quality of the bitumen.

The non-bituminous matter contained in coal tar is carbon, which is synonymous with lampblack and was, of course, a hydrocarbon before the hydrogen was eliminated by combustion. The carbon is insoluble in carbon-bisulphide or in the lighter coal-tar oils, while the bitumen is soluble in all of the *coal-tar oils*, naphtha, benzine, etc. Petroleum, light oils, or carbon-bisulphide, however, do not furnish a perfect solvent for *coal-tar bitumen*, but natural, illuminating, and water gases, all are solvents of the bitumens, either natural or artificial.

The process of collecting the tar from the coal is essentially the same by all processes of distillation, and consists in passing all of the vapors generated in the distilling chamber or vessel through a vertical stand-pipe which dips into a cold-water bath. The gas rises through the water and is conducted away for purification or use; while the condensed vapors of the tar, being of slightly greater density than the water (1.1 to water 1), sink to the bottom of the tank or condenser, and are drawn off as required. The greater part of the ammonia vapors are condensed and carried off in solution by the water of condensation and are recoverable. About 2 per cent. of carbon (lampblack) is generally carried by the tar. If more is present the process is deficient so far as making a good illuminating gas; as the excess of carbon caused by too high a heat in the distilling chamber consuming the lighter part of the carbon vapor, the resultant lampblack will pass onward with the gas, through all the purification and scrubbing processes, and will eventually reach the consumer's burners, causing annoyance in the form of stopped pipes and smoky ceilings.

If a refined coal-tar bitumen carries more than the above 2 or 3 per cent. of lampblack, the increase is probably an added prod-

uct, and is detrimental or not, depending upon the use to which the tar is put. As a brush or dip coating for iron work 10 or more percentage is allowable, particularly if the coating is to be applied warm or hot, to hot or warm bodies, and afterwards dried or cooled under like conditions. All bituminous coatings dry by evaporation, not by resinification, as do linseed oil coatings; hence the heat element in the drying of coal-tar coatings is not only favorable, but almost a necessary condition for success.

The application, as per page 815 (Pennock), appears to have been by heat, which was also probably the case noted at Potsdam. The tests on page 816 are all good indications of the protective value of the "Crysolite" coatings, but would have been of more value to the A. S. M. E. records had there been given the weight per gallon, covering power per gallon in square feet, cost per gallon, with other commercial data, the effect of it applied either under or over other coatings not of its own composition, whether driers can be used with it or not, and what kinds to meet the different requirements of winter or summer applications, or to get out of the way of a wet coat. Coal-tar coatings in general are the most unmanageable and unreliable of all ferric coatings. They require but a little alteration in the conditions under which they are applied, to utterly fail in the most unexpected manner and from apparently insignificant causes. It is a sad commentary upon the reliability of coal-tar products and their manufacturers, that in an industry a single branch of which in the United States reaches a total of 250,000 tons annually, there is not a large established firm in the country that maintains a laboratory alone equal to the task of putting upon the market even an approximately uniform bituminous cement or roofing tar. Chemical research has developed over 2,000 by-products from coal tar; the higher grade of these products are reliable and standard in character, but the lower-grade products receive only the most indifferent attention, and, as a consequence, there are many disappointments in their use.

Matheson ("Works in Iron") mentions a mixture for pipe coverings, consisting of 30 gallons of coal tar with all of its naphtha and oils retained, 6 pounds of tallow, 1½ pounds of some kind of resin, 3 pounds of lampblack, 30 pounds of freshly slacked quicklime mixed and applied hot. Its effect upon underground pipes was in a measure satisfactory, but in situations above

ground, in the open air, it cracked and shelled off any overlying paint not of its own composition in the liveliest manner possible.

Coal tar is acid in reaction. The addition of the lime in the above mixture was supposed to neutralize the acid elements, but it was sufficient to correct only about one-half of them, and with more lime the coating refused to spread or dip. The addition of lime to coal-tar mixtures only renders them difficult to apply and uncertain in their covering results. Thousands of feet of water pipes so coated and subsequently removed from the ground, have been found apparently in good condition with the coating in place and unbroken, but beneath the coating, corrosion of the pipe was in full progress, and the coating was in place simply for the reason that the corrosion had not acquired enough energy to cast it off against the pressure of the surrounding earth.

A recent letter from a prominent pipe founder in answer to an inquiry as to his method of protecting water pipes from underground corrosion, stated "that the method now pursued was to heat the pipes quite hot (about 600 degrees Fahr.), and dip them into the coal-tar bath, which was simply melted (possibly about 200 degrees Fahr.). The pipes were not left in the bath long enough to reduce their temperature to a point below where the coating will have a 'frying' appearance when lifted from the tar." This method seems to form as satisfactory a coating as anything known. Previous efforts with coal tar, linseed oil, and other mixtures only produced uncertain and unsatisfactory results.

A late pipe coating called "Assyrian rubber" (trade mark), composition unknown, appears to be impossible to apply so as to leave a neat-appearing surface. Its wearing or protective power, compared with the simple coal-tar coating, is yet to be determined.

"Crysolite" is said to be alkaline in reaction, hence will not attack any iron surface coated with it. If it can fill any one of the many gaps in the protective line of coatings, it will have a ready and hearty welcome from the whole engineering fraternity, but at present more light is needed relative to its composition and behavior in more than one situation.

The reference by Mr. Long to the want of knowledge on the part of the writer concerning the various supplies and uses of graphite, can possibly be attributed to the fact that such knowledge as he has at command has been acquired as an engineer and

user of protective paints, instead of a manufacturer of them. If the writer's theory of paints and painting, as expressed in this and former papers presented to this Society, is wrong, he is not so firmly attached to his convictions as to be incapable of enlightenment, but what he has set forth is the result of his own experience and observation on the practice of others. The best methods and the best auxiliaries to reach a perfect result in a protective coating are what the writer is in search of; whether that auxiliary is a pigment 70 years or 70 days old is not the question at issue. In regard to silica graphite paints, there are a dozen of them with as varied degrees of excellence as any other of the commercial paints, and the writer, upon review of the paper, sees no reason to modify paragraphs 25, 26, and 27 in any particular. That the practice of using the best brand of graphitic carbon procurable, also of silica, separately pulverized and afterwards mixed in some proportion and ground in the oil, furnishes a good paint, cannot be and is not denied, but that it is as good a product as it would be were the 20, 30, or 50 per cent. of silica combined by nature with the graphite (whatever its quality) instead of being artificially mixed is doubtful. The flake graphite and the silica have no chemical affinity for each other, and cannot be combined other than by nature's processes in any manner nor in any degree, so that any quality in the one could support or fill any deficiency of character in the other. Hence, with a given compound of two, three, or more mineral substances, even if in the proper proportion (if that can be, or ever has been ascertained), and the best that could be devised for a required purpose, the mixture that held these substances compounded by nature always has been and ever will be superior to the artificial amalgamations, however carefully prepared and honestly presented to the public. The two products are not identical, other than that, in general, they contain the same individual substances; whether they were gathered at the poles of the earth or the equator does not bear upon the matter, neither does that of how long they have been known to commerce. Graphitic carbon will always be recognizable wherever found, and in whatever amount it is associated with other minerals.

Graphitic carbon is widely diffused in nature. It is a component part of cast iron as it leaves the blast furnace, and alters its appearance, if not its character, according to the degree of heat employed in the reduction of the iron ore, and casting the

metal into pigs. The same metal cast at the same moment into the sow or the pig, often presents widely different *appearances* if not compositions. Graphitic carbon is an intermediate carbon, between anthracite and bituminous coal, presenting some features of each and some features wholly unlike them or those of its next neighbor, lampblack.

What the exact proportions of graphitic carbon and other mineral substances are, and what the nature of the substances are to make a perfect ferric protective coating, is not now known, but we do know that a mineral containing 30 to 50 per cent. of graphitic carbon naturally combined with silica, calcium, magnesia, and other substances that have not been made caustic by calcination, form durable and reliable ferric coatings, even if their advent and use as such is comparatively of recent date. That these amorphous or granular graphite minerals can be easily ground to the requisite fineness for a pigment, is as universally admitted as their excellence when so prepared. The writer accepts the correction in paragraph 27 that the purer forms of graphitic carbon, especially flake graphite, cannot be ground other than in a flake form. In some experiments of his own he found that, by long titration in water, the graphite could be reduced to the necessary fineness for a pigment, but the added element of water brought another difficulty into the field, as the moisture, if not entirely evaporated, prevented the graphite from bonding to the oil in any degree, and the graphite flakes floated around in the oil menstruum like so many water-soaked wooden chips in a bed of soft mud. Silica and other mineral adulterants, even to the extent of 40 per cent., did not wholly prevent the movement in the paint, so much complained of by painters using the so-called silica graphite paints.

Granted that improved processes in grinding the flake graphite result in the necessary fineness without the use of water in the mill, it in no manner ensures the stability of graphite atoms in the drying coat of paint, whether their form is granular or flake, without the presence of holdfast adulterating substances, that of themselves contribute nothing to the durability, color, or protective nature of the coating, however they may arrange themselves with the graphite atoms, in sequence or not.

An ideal pigment atom which should assume the form of a slab to be laid by a crowbar and trowel, or even like a slate embedded in mortar on a roof, the writer concedes would be a far better

protection than a group of pigment atoms, whatever their form, floating in a bath of oil and put into place by a brush, but he imagines there might arise some difficulty in applying the new ideal to many situations where the brush-laid compounds thus far have held the field.

As a fact, the silica and graphite paint compounds on flat or not steeply inclined metallic roofs are the best of all paints, as they are not only of good body, but they do not dry down as quickly or as hard as other paints, and they follow the expansion and contraction of the metallic roofing due to the changes in the temperature, far better than the iron oxide paints in general use for roofing purposes. In this case the heavier the coating and the more deeply the graphite and silica atoms are embedded in the menstruum the more durable will be the coating.

Instances are quoted where graphite and silica pigments have been mixed with crude petroleum, and then spread over ferric bodies that subsequently were immersed in salt or fresh water for many years, perfectly protecting the covered ferric surface. The immersion of such compounds is their salvation. In the open air or under ordinary atmospheric exposure, such mixtures dry by the evaporation of the lighter part of the petroleum oil (the naphtha, benzine, etc.), and not by any process of resinification, as is the case with linseed oil. They "peel" just as soon as the coating has dried enough to hold together for the stripping process. They are not paints in any sense; that word is used to denote a fluid mixture that can be applied with a brush to cover any wood, metal, or other surface, and their uses are exceptional. Probably the substances to which they were applied would have been as well preserved and certainly more cheaply covered by a coating of hydraulic cement.

The oil repellent properties of flake graphite are at once apparent in such mixture. Iron oxide and silica mixed with the same petroleum oils are less liable to peel in open-air exposure than the graphite, and under water they appear to be equally efficient in protecting the covered surface. In fact, silica alone with petroleum makes a good under-water coating if strong driers have been added to the oil to get the necessary initial set of the coating. The same driers would have to be used if graphite was also present, as there is no drying element in either the graphite or silica pigments.

The remarks upon the laboratory tests in paragraph 31 in con-

ground, in the open air, it cracked and shelled off any overlying paint not of its own composition in the liveliest manner possible.

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"Crysolite" is said to be alkaline in reaction, hence will not attack any iron surface coated with it. If it can fill any one of the many gaps in the protective line of coatings, it will have a ready and hearty welcome from the whole engineering fraternity, but at present more light is needed relative to its composition and behavior in more than one situation.

The reference by Mr. Long to the want of knowledge on the part of the writer concerning the various supplies and uses of graphite, can possibly be attributed to the fact that such knowledge as he has at command has been acquired as an engineer and

user of protective paints, instead of a manufacturer of them. If the writer's theory of paints and painting, as expressed in this and former papers presented to this Society, is wrong, he is not so firmly attached to his convictions as to be incapable of enlightenment, but what he has set forth is the result of his own experience and observation on the practice of others. The best methods and the best auxiliaries to reach a perfect result in a protective coating are what the writer is in search of; whether that auxiliary is a pigment 70 years or 70 days old is not the question at issue. In regard to silica graphite paints, there are a dozen of them with as varied degrees of excellence as any other of the commercial paints, and the writer, upon review of the paper, sees no reason to modify paragraphs 25, 26, and 27 in any particular. That the practice of using the best brand of graphitic carbon procurable, also of silica, separately pulverized and afterwards mixed in some proportion and ground in the oil, furnishes a good paint, cannot be and is not denied, but that it is as good a product as it would be were the 20, 30, or 50 per cent. of silica combined by nature with the graphite (whatever its quality) instead of being artificially mixed is doubtful. The flake graphite and the silica have no chemical affinity for each other, and cannot be combined other than by nature's processes in any manner nor in any degree, so that any quality in the one could support or fill any deficiency of character in the other. Hence, with a given compound of two, three, or more mineral substances, even if in the proper proportion (if that can be, or ever has been ascertained), and the best that could be devised for a required purpose, the mixture that held these substances compounded by nature always has been and ever will be superior to the artificial amalgamations, however carefully prepared and honestly presented to the public. The two products are not identical, other than that, in general, they contain the same individual substances; whether they were gathered at the poles of the earth or the equator does not bear upon the matter, neither does that of how long they have been known to commerce. Graphitic carbon will always be recognizable wherever found, and in whatever amount it is associated with other minerals.

Graphitic carbon is widely diffused in nature. It is a component part of cast iron as it leaves the blast furnace, and alters its appearance, if not its character, according to the degree of heat employed in the reduction of the iron ore, and casting the

ground, in the open air, it cracked and shelled off any overlying paint not of its own composition in the liveliest manner possible.

Coal tar is acid in reaction. The addition of the lime in the above mixture was supposed to neutralize the acid elements, but it was sufficient to correct only about one-half of them, and with more lime the coating refused to spread or dip. The addition of lime to coal-tar mixtures only renders them difficult to apply and uncertain in their covering results. Thousands of feet of water pipes so coated and subsequently removed from the ground, have been found apparently in good condition with the coating in place and unbroken, but beneath the coating, corrosion of the pipe was in full progress, and the coating was in place simply for the reason that the corrosion had not acquired enough energy to cast it off against the pressure of the surrounding earth.

A recent letter from a prominent pipe founder in answer to an inquiry as to his method of protecting water pipes from underground corrosion, stated "that the method now pursued was to heat the pipes quite hot (about 600 degrees Fahr.), and dip them into the coal-tar bath, which was simply melted (possibly about 200 degrees Fahr.). The pipes were not left in the bath long enough to reduce their temperature to a point below where the coating will have a 'frying' appearance when lifted from the tar." This method seems to form as satisfactory a coating as anything known. Previous efforts with coal tar, linseed oil, and other mixtures only produced uncertain and unsatisfactory results.

A late pipe coating called "Assyrian rubber" (trade mark), composition unknown, appears to be impossible to apply so as to leave a neat-appearing surface. Its wearing or protective power, compared with the simple coal-tar coating, is yet to be determined.

"Crysolite" is said to be alkaline in reaction, hence will not attack any iron surface coated with it. If it can fill any one of the many gaps in the protective line of coatings, it will have a ready and hearty welcome from the whole engineering fraternity, but at present more light is needed relative to its composition and behavior in more than one situation.

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Graphitic carbon is widely diffused in nature. It is a component part of cast iron as it leaves the blast furnace, and alters its appearance, if not its character, according to the degree of heat employed in the reduction of the iron ore, and casting the

supplies, etc. In this period, 1,470,000,000 gallons were filtered, the average cost per million gallons being, therefore, $4.19. The average cost per million gallons of the operation of the pumping stations was $2.52, leaving $1.67 to represent the cost of operating the filters, including the laboratory work. The pumping cost was 14 cents per 1,000,000 gallons raised one foot.

The engines were originally provided with a receiver between the high and low pressure cylinders, but this was removed before the tests were started.

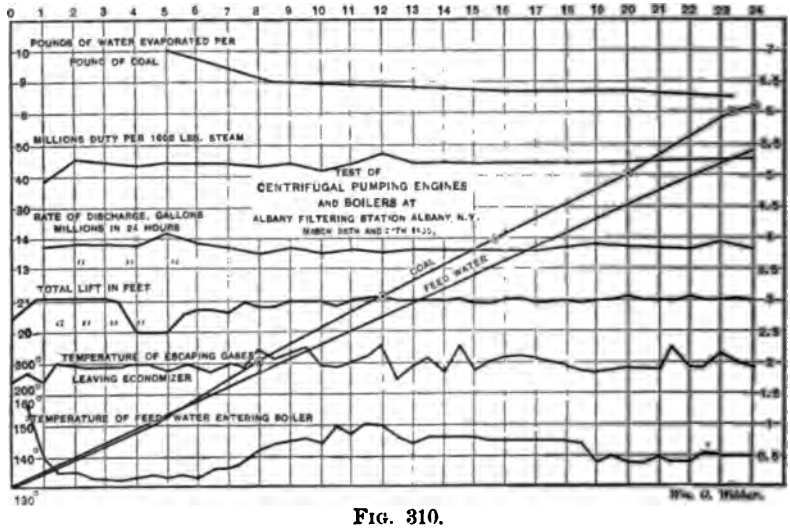

POUNDS OF WATER EVAPORATED PER POUND OF COAL
MILLIONS DUTY PER 100 LBS. STEAM
TEST OF
CENTRIFUGAL PUMPING ENGINES
AND BOILERS AT
ALBANY FILTERING STATION ALBANY N.Y.
RATE OF DISCHARGE, GALLONS MILLIONS IN 24 HOURS
TOTAL LIFT IN FEET
COAL
FEED WATER
TEMPERATURE OF ESCAPING GASES LEAVING ECONOMIZER
TEMPERATURE OF FEED WATER ENTERING BOILER

FIG. 310.

A twenty-four-hour test on the No. 2 boiler, pump, and engine was made by Allen Hazen, C. E., of New York, and the writer.

The drips from the engine were disconnected and showed no leaks of steam. The blow-off from the boiler was disconnected and found to be perfectly tight. The No. 1 boiler was blank flanged, and a steam pipe led from this No. 1 boiler to an auxiliary pump, which was used to pump the feed water into the weighing tanks.

A running start was made with about 3 inches of fire above the grates at 12.30 P. M., Monday, March 26th, there being just 13 inches of water in the water glass on the boiler. These conditions were maintained constantly and exceedingly uniform for

the next twenty-four hours, ending 12.30 P. M., Tuesday, March 27th.

The results of these tests are given in the following tabulation, but might be explained more in detail as follows to those who are not entirely familiar with the technical items used in pump tests:

The net work done in a twenty-four-hour test (Item 18) represents the total number of pounds of water at the temperature of 34 degrees Fahr. (Item 7) elevated to the total height of pumping, 20.92 feet (Item 16). The duty per 1,000 pounds of feed water (Item 19) is obtained by dividing the net work, 2,400,130,680 pounds, by the total number of pounds of feed water consumed, and multiplying by 1,000. Item 25 being the amount of feed water consumed per hour, the total feed water consumed was $2,243.5 \times 24 = 53,744$ pounds, hence Item 19 is $\frac{(44,574,801)}{(53,744)} 1,000 = 44,574,801.$

Item 20, the duty per 100 pounds dry coal, is a similar result obtained by dividing Item 18 by the total number of pounds of dry coal burned, and multiplying the result by 100.

Item 21, the piston speed of engine, is the stroke of the engine in feet multiplied by two (2), and by the number of revolutions per minute (Item 13).

Item 22, the average indicated horse-power of the engine, represents the average indicated horse-power developed by the engine during the test, the diagram being taken at intervals of one hour, and engines running uniformly.

Item 23 is the equivalent of 9,550 gallons of water per minute at a temperature of 34 degrees, which would equal a weight of 62.42 pounds per cubic foot raised to the height given, converted into horse-power. In other words, Item 23 represents the actual work done and Item 22 the indicated horse-power required to be developed to do this work.

Item 24, which is Item 23 divided by Item 22 and multiplied by 100, represents the efficiency of the pumps and engines.

Item 25 explains itself.

The following ten (10) items are all estimated, Item 26 representing the horse-power at 34½ pounds of steam required to operate the condenser and boiler feed pump, and being estimated on the basis of 120 pounds of steam per horse-power per hour required to operate these pumps.

Item 27 is the pounds of dry coal burned per horse-power per hour under the boilers, divided by the sum of Items 22 and 26.

Item 28 is the feed water per hour divided by the same sum.

Items 29 and 30 are respectively the feed water per hour separated so as to show what part belongs to the condenser and boiler feed pumps and what part to the main pumping engine.

Item 31 is to show the consumption of coal per hour required to operate the condenser and boiler feed pumps.

Item 32 is the same as Item 19, excepting that it is figured for the main engine alone, and the steam required to operate the condenser and boiler feed pumps is taken out of it so as to show the efficiency of the main pumping engine alone, the 1,000 pounds of steam being the same as 1,000 pounds of feed water.

Item 33 is similar to Item 20, with the exception just made above for Item No. 32.

Item 34 is from indicator cards, which show the friction of the engine driving itself and the pump running empty.

Item 34a is the work done in Item 23, divided by the average indicated horse-power of the engine Item 22, minus the friction of the engine and pump running empty (Item 34), and is stated to show what the actual net efficiency of the pump itself, as a means of elevating water, is.

Item 59 is the total heat necessary to raise 1 pound of water from the temperature of the feed to steam of the pressure noted in Item 35, multiplied by the amount of feed water evaporated into steam of the pressure noted from water at a temperature of 212 degrees for each pound of coal, with the ashes and the moisture of the coal deducted, and is known as the British thermal units actually derived from 1 pound of combustible.

Item 60 is the equivalent evaporative power of 1 pound of Reynoldsville coal as determined by a calorimeter.

Item 61 is the proportion that Item 59 bears to Item 60.

DUTY TRIAL OF ENGINES AND PUMPS.

Dimensions:

1. Number of steam cylinders	2
2. Diameter of steam cylinders, inches	10, 18
3. Diameter of piston rods, inches	1¼
4. Stroke of engine, inches	20

5.	Delivery diameter centrifugal pumps, inches	24
6.	Diameter of centrifugal pump discs, inches	42
	Temperature:	
7.	Of water in pump well, degrees Fahr	34
8.	Of water entering economizer, degrees Fahr	82.5
9.	Of water entering boiler, degrees Fahr	142.7
	Average Pressures:	
10.	Boiler pressure by gauge, pounds	126
11.	Vacuum at engine by gauge, pounds	24.5
	Miscellaneous Data:	
12.	Duration of trial, hours	24
13.	Average revolution per minute of engine and pump, number	214
14.	Moisture in steam, per cent	1.4
15.	Mean effective pressure from indicator, diagrams, high-pressure cylinder, pounds	40.9
	As above, low-pressure cylinder, pounds	15.52
16.	Average height of pumping, feet	20.92
17.	Total water pumped, gallons	13,740,000
	Principal Results:	
18.	Net work done in 24-hour test, foot-pounds	2,400,130,680
19.	Duty per 1,000 pounds feed water, foot-pounds	44,574,801
20.	Duty per 100 pounds dry coal, foot-pounds	40,610,000
21.	Piston speed of engine, feet	355.24
22.	Average indicated horse-power of engine	76.16
24.	Efficiency of pumps and engines, per cent	50.5
25.	Feed water consumed per hour, pounds	2,243.5
	Estimated Results:	
26.	Horse-power of condenser and boiler feed pumps	10.485
27.	Dry coal used per total horse-power per hour, pounds	2.843
28.	Pounds of water evaporated per total horse-power per hour from feed at 142.7 temperature to steam at 126 pounds pressure	25.9
29.	Feed water per hour condenser and boiler feed pumps, pounds	629
30.	Feed water per hour main engine, pounds	1,614.5
31.	Dry coal per hour, condenser and boiler feed pump, pounds	69.9
32.	Duty of main engine alone for 1,000 pounds steam, foot-pounds	61,970,000
33.	Duty of main engine alone for 100 pounds of coal, foot-pounds	56,708,000
34.	Friction engine and pump running empty, horse-power	10.57
34a.	Net efficiency of pump alone, per cent	77

BOILER TEST.

	Average Pressures:	
35.	Of steam in boiler by gauge, pounds	126
36.	Atmospheric pressure, barometer, inches	29.72
	Temperatures:	
37.	Of steam, degrees Fahr	344.73
38.	Of escaping gases, degrees Fahr	299.7
39.	Of feed water entering economizer, degrees Fahr	82.5
40.	Of feed water entering boiler, degrees Fahr	142.7
41.	Of boiler and engine-room, degrees Fahr	68
42.	Of outside air, degrees Fahr	34.5

Fuel:	
43. Total amount of coal consumed, pounds	6,[illegible]
44. Moisture in coal, per cent	5
45. Dry coal consumed, pounds	5,910.9
46. Total refuse dry, pounds	[illegible]
47. Total refuse, per cent	4.77
48. Dry coal used per hour, pounds	246.29
49. Total combustible, pounds	5,6[illegible].9
Quality of Steam:	
50. Moisture, per cent	1.4
51. Factor of evaporation, per cent	1.1173
Water:	
52. Water pumped to boiler and apparently evaporated, pounds	5[illegible],345
53. Equivalent water evaporated into dry steam, pounds	5[illegible],[illegible]33
54. Equivalent water evaporated into dry stream from 212°, lbs.	59,300
55. Equivalent water evaporated into dry steam from 212°, per hr.	2,471
Economic Evaporation:	
56. Water actually evaporated from dry coal, pounds	8.96
57. Equivalent water evaporated from dry coal from 212°, pounds	10.0[illegible]3
58. Equivalent water evaporated per lb. combustible from 212°, lbs.	10.5[illegible]5
Efficiency of Boiler:	
59. Total heat derived from coal, British thermal units	10,173
60. British thermal units in coal (calorimeter)	14,[illegible]80
61. Efficiency of boiler, per cent	69.77

DISCUSSION.

Mr. E. T. Adams.—I believe that future searchers in the index of these *Transactions* would be grateful to Mr. Webber if he would change the title of his paper sufficiently to indicate that it was largely a record of a test on a centrifugal pumping engine at the Albany Filtration Plant.

The conditions at this plant, as given by Mr. Webber, seem to be ideal for high efficiency, either on a twenty-four-hour trial or under usual working conditions. There are two units. The average load is practically that which gives maximum efficiency for one. There is storage capacity at the station equal to about one-third the daily demand, which should protect the station from serious fluctuations in load, and the water is clear and allows the design of a pump which will give maximum efficiency. In this respect Mr. Webber has done his part in providing a centrifugal pump with 77 per cent. hydraulic efficiency, but it would be interesting to know on what grounds the engineer who designed the plant as a whole would justify a choice of motor

which only gives 40,610,000 foot-pounds duty per 100 pounds of dry coal, a duty fully 60 per cent. less than one has a right to expect from a properly designed plant of this type, considering all the conditions at the time of the test.

Mr. Webber does not give the duty actually obtained under every-day conditions, or the itemized costs of pumping—possibly he may be able to supply this later—but judging from the total pumping cost of 14 cents per million foot-gallons, the duty of the plant under actual running conditions cannot greatly exceed 20,000,000 to 25,000,000 foot-pounds per 100 pounds of coal. This pumping cost is anywhere from 50 to 100 per cent. too high, and represents an annual loss, as near as one can estimate from the data which Mr. Webber has supplied, just about equal to the first cost of the engine.

Many people seem still to hold the belief that a centrifugal pump is a very inefficient machine, and on some principle relating to the eternal fitness of things, such a one would hold that any motor was good enough to drive a centrifugal pump. I do not wish to make any extravagant claims for centrifugal pumping engines. Such engines certainly have their limitations, both as to range of usefulness and efficiency. I merely wish to emphasize the fact that this is not a typical example of good practice. The duty per 100 pounds of coal is 40,610,000 foot-pounds. I will append some figures showing that it should be 100,000,000 foot pounds. The cost per million foot-gallons is 14 cents; it should not exceed 10 cents on the same basis, even under typical municipal management.

The Allis Company do not build centrifugal pumps, except specially designed pumps for special cases, and have never built any such pumps for ordinary city water supply. But they have built a great many centrifugals, mostly of large size, for handling sewage and for drainage purposes, and the figures which are given below are taken from the duty trials, and the average yearly record of some sewage pumps built four or five years ago for the city of Boston. The conditions here were not at all favorable to high duty, either on a 24-hour test or under regular working conditions, the reasons being, first, that a sewage pump cannot always be designed primarily for high duty, but must be designed to pass large objects without clogging, and efficiency becomes in a way a secondary consideration; and, second, unlike the Albany plant, there is no great reservoir interposed to take

care of any fluctuation in the quantity of sewage. As fast as this comes it must be lifted to the high-level discharge. At some periods of the day all the pumps will be required to handle the flow, and at other times a single pump will be running on friction load, picking up a load for five-minute periods three or four times in an hour. This of course is very wasteful; but at these periods the flow of sewage is so variable that it is found cheaper to keep running than to shut down, bank fires, and wait for the sewers to fill up.

There are three 36-inch centrifugal pumps, each direct-coupled to a triple-expansion engine, and six 48-inch centrifugal pumps, also direct-coupled to triple-expansion engines.

On a 24-hour-duty trial the average duty of the small engines and pumps was 90,000,000 foot-pounds per 100 pounds of Cumberland coal, with no deductions of any kind. The 48-inch sets, engines and pumps combined, gave an average duty of 93,000,000 foot-pounds.

For the year 1900 the output in million foot-gallons for the three 36-inch Boston pumps is somewhat lower than that for the two 30-inch pumps at Albany, yet with such exceedingly unfavorable conditions as to load, the average duty for the year is over 51,000,000 for the 36-inch Reynolds pumps, and over 53,000,000 for the larger Reynolds pumps. That is, the yearly average duty of these pumps is about 30 per cent. higher than the duty reached at Albany in a 24-hour test under ideal conditions.

The cost per million foot-gallons with $4.50 coal and city management was 10.8 cents for the small pumps, and 6.5 cents for the large pumps. I regret that I have not the data from which to make a comparison, taking in depreciation, repairs, and interest on investment, but a comparison of the figures given indicates that a more economical motor could easily make enough saving in a very few years to more than pay for itself.

In conclusion, I wish again to emphasize the fact that the low duty recorded is a result for which Mr. Webber is in no part responsible, and also to point out that I do not find fault with the motor in itself. The engine used is a splendid example of its type. I wish simply to bring out the folly of adopting this type for a service for which it is in every way unfitted.

*Mr. William O. Webber.**—The actual duty obtained on the

* Author's closure, under the Rules.

Albany Pumping Plant under every-day conditions was about 31,000,000 foot-pounds previous to the changes made by the writer in the engines before the tests were made. There is no reason now why a duty of at least 40,000,000 foot-pounds should not be obtained under every-day conditions.

I have noted with a great deal of interest the figures which Mr. Adams contributes regarding the triple-expansion pumping engines built for the City of Boston Sewerage Department, and which Mr. Allen thinks were tested under such unfavorable conditions.

The only comments which I desire to make on the tests from which he quotes are these:

An engine developing as low as 76 horse-power, being Engine No. 1 at Charlestown, is made to show the remarkable result of 1.096 pounds of dry coal per horse-power per hour.

Engine No. 2 at East Boston, developing 238 horse-power, shows 1.17 pounds of dry coal per horse-power per hour; and

Engine No. 2 at Deer Island 1.33 pounds of dry coal per horse-power per hour. These results are so remarkable that any duties based upon them require an explanation of how it is possible to obtain such low fuel consumptions from engines of so small capacities.

The writer agrees very fully that the type of engine used at Albany was not the most economical, or one which he should adopt for the services there required, if unfettered by first cost. He also agrees that it would be rather better if the title of the paper was changed to read "Record of a Test on a Centrifugal Pumping Plant at the Albany Filtration Station."

No. 903.*

THE LOCOMOTIVE EXHIBITS AT THE PARIS EXHIBITION OF 1900.

BY STORM BULL, MADISON, WIS.

(Member of the Society.)

1. HAVING been a member of the international jury of awards at the last exhibition at Paris, and having spent, as such, some two months and a half there last summer, it was thought by an officer of our Society that I could furnish a review of the transportation exhibits for its *Transactions*, notwithstanding the fact that I was not a judge in the line of railway exhibits, nor can lay claim to a special competency in that line. I desire also to state at this place, that if I had known during my stay at Paris that I should be called upon to write a paper upon this subject, I should have taken pains to collect material for it over there, especially in the line of illustrations. As it is, I have to be satisfied with the illustrations which I have been able to gather from various sources.

I desire also to state that I have limited my paper to locomotives, and, therefore, do not include such subjects as cars, automobiles, and bicycles, which all properly belong to the transportation exhibits. Each of these subjects should be treated in a separate paper, and there is no question that, especially with respect to automobiles, the last exhibition at Paris contained such a vast amount of interesting material that it is a pity that the *Transactions* of the Society should not contain a review of the status of this new line in the methods of transportation at the close of the nineteenth century.

2. The railway exhibits were nearly all installed at the annex of the exhibition at Vincennes. A number of the large railway companies in Europe, and especially of France, had exhibits at the main building of the Champ de Mars, but these consisted principally of photographs, drawings, and statistical documents. The only loco-

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*

motive outside of Vincennes was one exhibited by Schneider & Cie., of Creuzot, France, at their large pavilion on the bank of the Seine near the Champ de Mars.

A special building had been erected at Vincennes to house the locomotives and cars exhibited. It consisted of ten sheds built next to each other and containing each two tracks, the total length of tracks being about 11,000 feet. The building was very light and airy, the only objection to it being that in stormy weather rain would occasionally find its way through the skylights, to the great detriment of the polished machinery. The space had been distributed among the various nations after a protracted fight, and I am sorry that I have to state that the United States had made a poorer use of the allotted space than any other nation, probably because of the failure of parties who had promised to exhibit. Compared with the immense importance played by the railway companies and by the manufacturing interests in this line in the United States, our part in the transportation exhibits was lamentably small. This is greatly to be regretted, as without question there are few lines in which, according to universal opinion, we show such superiority over European nations. It is also a fact that one of the branches of the exhibition at Chicago in 1893 which impressed the foreign visitors most vividly was our transportation exhibits, and this was also very apparent from the exhibits of several continental nations at Vincennes. One could not help noticing that American ideas had been made use of in a great many ways, and from conversation with interested parties it was soon learned that the Chicago Exhibition was responsible for a large share of the changes noticed.

I think it was a very common opinion of European visitors to the Paris Exhibition that it was not very striking in the line of transportation exhibits, and this again is explained by the same fact that they compared the transportation exhibits from the United States at Paris with those at Chicago, where the European visitors had received such a strong impression of the superiority of our railway appliances in general. But, on the other hand, if the exhibition was not very striking, it was both very large and fine. That it was large will be realized at once from the fact that it contained 66 different locomotives and 165 cars of various kinds. The space allotted—especially to France and Germany—was very crowded, and I was informed that both countries had to refuse interesting exhibits because of lack of space, which might easily have been supplied by both the United States and Russia, the two nations which, it

was very apparent, on all occasions received the highest favors from the French—both officially and unofficially.

3. Before passing on to the subject of this paper, it is, perhaps, proper first to state that it was very unfortunate that it was found necessary to locate the transportation exhibits at Vincennes—some seven miles from the main part of the exhibition. From the statistics of the entries to the exhibition it is plain to see that not one-tenth of the whole number of visitors ever came to Vincennes, the reason being principally that the distance was so great that it took about an hour and a half to go from Champ de Mars to Vincennes; and then if a visitor managed to get to the park of Vincennes, it was even then quite difficult to find the various exhibits located there, the part of the park set apart for exhibition purposes being very large, and with its winding paths giving one the impression of a labyrinth, in which it was quite difficult to go from one building to the next. It is not to be wondered at, therefore, that all exhibitors who had to place their exhibits at Vincennes complained bitterly, and the only excuse for the authorities responsible for this state of affairs must be sought in the fact that the call for space was so much larger than anticipated, so that it was impossible to find room for all at the main exhibition grounds.

To an American there were certainly a great many new and unusual things to see among the exhibits at Vincennes. European practice, both in locomotive and car building, is so very different from that in the United States, and as more than nine-tenths of the exhibits were of European origin, the large array of engines and cars certainly presented an unusual appearance. But there were also quite a few novelties in design, and it is my opinion that several of these really were decided improvements over the ordinary types. However, the first strong impression an American visitor would get by viewing the European locomotives was that their size had been very greatly increased in the last few years. Persons who had been familiar in the past with European engines knew that these had always been very much smaller than those in the United States—that in fact they looked like dwarfs compared with the latter. But at Vincennes a large number of those exhibited could very well be compared with our own as to size and capacity. This is especially true with reference to passenger engines, the large size of these having become a necessity because of the high speed and great weight of a number of express trains now being run in various countries, especially in France, Great Britain, and Germany. Even

Russia exhibited some very large engines, one especially which, if I am not mistaken, was the largest of the whole exhibition, with the exception of the one exhibited by the Creuzot Works at the Champ de Mars.

Another feature which one could not help notice at once was that fully one-half of all the locomotives exhibited were compound. It is probably also true that about half of all the engines built now on the continent of Europe are compounds, so that the exhibition gave a true picture of this industry. In this respect I think that they are ahead of us, as, although some railroads in this country are getting quite a good many compounds, in the majority of cases it seems that an ultra-conservatism keeps us back. This statement assumes, of course, that the compound locomotive is an advance over the single expansion one, and this opinion is now backed by nearly all competent authorities in Europe, possibly outside of Great Britain. The statement ought, however, to be qualified to this extent, at any rate, that it does not apply to all kinds of service, but certainly to all through trains. There were compound engines shown of every conceivable design and combination; with two, three, and four cylinders, and these arranged like the Vauclain, or two inside and the two others outside the frame; or again, as on a Russian engine, tandem fashion outside the frame. On the French compounds the de Glehn system seemed almost universally in use. In this the high-pressure cylinders are placed outside of the frame, somewhat behind the smoke-box, whereas the low-pressure cylinders are placed inside the frame and directly below the smoke-box, and they are coupled with a different pair of driving wheels from that to which the high-pressure cylinders are coupled. This system was, as is well known, first adopted by the Northern Railway of France, but has since been introduced into all of the French railway companies, including those belonging to the state, and it is the universal opinion that these engines are doing excellent service. Engines of this kind are now pulling the fastest long-distance train in the world—the fast express between Paris and Bayonne, in southern France. As a matter of fact, it may be stated that nearly all the fast trains in France are at the present time being pulled by compound engines. The objection which has been advanced by so many in this country against the compound locomotive—that it costs so much to keep it in repair—has certainly been overcome by the continental designs, as is proven by the records of these engines during the last few years.

As is well known, the valve gears on nearly all continental engines are placed outside the frame, at least where the cylinders are placed outside the frame. This was also the case with the engines exhibited at Vincennes. This peculiarity is, presumably, due to the fact that continental designers almost always use the Walschaert valve motion, for which it is almost necessary to be next to the crosshead. This universal use of this valve motion is rather striking in view of the fact that it has, to a great extent, replaced the Stephenson motion, although this never was in such a universal use as it is here in the United States. There is no doubt that the placing of all these levers and links which are necessary for the Walschaert motion outside of the frame and drivers makes them very liable to injury when the smallest accident occurs. On the other hand, the designers insist that they can get better results as to steam distribution with it than with the Stephenson motion, and all these polished levers, cranks, and links in plain sight certainly look very pretty. The contrast to this arrangement is, as is well known, found in the English locomotives, where everything is concealed behind the frames. Some engines of this type were also exhibited by other countries—notably from Switzerland—but taking it altogether it seems that this is destined to remain the peculiarly English type. It might, perhaps, be appropriate to state at this place that the English exhibit in this line was rather better than in almost all other directions, the exhibit of England being in general, as is well known, very poor, so that even its railway exhibit did not come up to what one had the right to expect from a country like England, which in times past has supplied so many countries of the globe with locomotives and cars. England exhibited only five engines, all of which, however, were very fine-looking specimens, and of which only one was a compound of the Webb type. In this respect it seems that England is very conservative as compared with continental nations. It could not help being noticed that even England exhibited only one single-coupled engine, whereas only a few years ago nearly all their engines for fast passenger service were of this type, just as in France this type seems to have been abandoned in favor of the four-coupled engine. If I remember correctly, there was but that one engine with one driving axle exhibited, so that it is very plain that in this respect our practice of having four-coupled driving wheels for our passenger engines has won over the whole line. It ought, perhaps, to be stated that the sudden and rapid introduction of this type into France is, to

a great extent, due to the fact that the de Glehn compound has become the standard for all heavy and fast passenger service in that country, and for this type of compound engines two driving axles are, as is well known, a necessity.

Nearly all the engines exhibited presented a very tasty appearance. Presumably, most of them had been built and finished specially for the exhibition, and this may, to a certain degree, account for the uniformly high finish of nearly all engines shown. However, there was a good deal of difference also in this respect between the various exhibits, and it is the writer's opinion that in the line of locomotives, perhaps as much as in the line of steam engines, the finish of the Swiss locomotives, those shown by the Winterthur Locomotiven Fabrik had the most beautiful finish of any shown at the exhibition. The writer has heard people speak with a kind of contempt of this " watch finish," as they call it, and he has also seen the same in print. But, nevertheless, he cannot help but admire it. As he has stated in another paper, such finish does not make the engine essentially better, but it looks better, and if such finish can help the sale of an engine it certainly should be put on. The argument is of course that the engines shown at Vincennes had been finished much better than the ordinary engines built. This is, as stated before, no doubt true to a certain extent, but the fact remains the same, nevertheless, that the best European engines are better finished than the best from the United States as they are both built in ordinary practice. Some people have imagined that the finish consists simply in leaving more of the parts bright and not painted. This is, at any rate, not the opinion of the writer. A certain number of parts must of necessity be left bright, and the difference in finish will at once be apparent from the different degree of smoothness of the surfaces. But, in addition, a difference in finish will perhaps be even more apparent from the degree of smoothness of the painted surfaces both of the stationary and moving parts, and anybody who at all examined the locomotive exhibits at Vincennes could not help noticing the beautiful smooth surface of the painted parts of a good many of the European locomotives, and, as I must say to my great regret, in contrast with those exhibited from the United States, these latter being in every other respect fully the equal of the former. It would not, perhaps, be policy to mention these facts here, except for the reason that also in other lines of machinery the exhibition showed that we did not put as much work on our machines for finish as most of the foreigners do, and

as they seem to demand over there, and because of this it seems to the writer that one of the lessons which we should try to learn from the last exhibition is that, if we desire to increase our export trade in machinery in general, we should try to finish the products in several lines—not in all—better than we do at present. The writer has heard this from disinterested persons from various nations at Paris last summer, and he feels it his duty to repeat it here.

The number of locomotives exhibited was, as stated before, 66, the number contributed by the various countries being as follows:

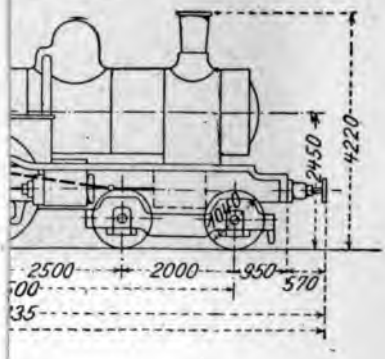
France, 16; Germany, 14; Austria, 6; Belgium, 6; Switzerland, 5; Russia, 5; Great Britain, 5; Hungary, 3; Italy, 3; and the United States, 3. Of these locomotives there were 57 for standard gauge and 9 for narrow gauge of various widths. Of the 57 locomotives for standard gauge there were 32 for express service, 3 for ordinary passenger service, 11 freight locomotives, 10 tank locomotives, and 1 for mountain service for rack railway. Of the narrow-gauge locomotives 7 were tank locomotives and the other 2 were provided with separate tenders.

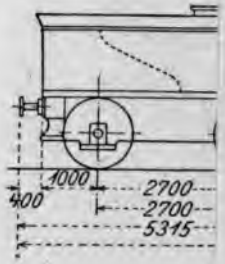
There were in all 34 compound locomotives, or 1 more than half of the total number exhibited. Of these only 1 was for narrow gauge, 17 of the compounds had four cylinders, and 14 of these again were designed for fast passenger service, the 3 others for freight service. There was 1 compound with 3 cylinders, this one being designed for ordinary passenger service. There were 15 compound locomotives with 2 cylinders, of which 7 were to be used for express service, 2 for ordinary passenger service, 5 for freight trains, and 1 was a tank locomotive.

Twenty-one of the locomotives had four-coupled wheels and had, besides, 2 other axles, 18 of these 21 being destined for express service. It will be noticed from this that this type of engine, which is now so very popular in this country for passenger service, is also becoming the prevailing type in Europe.

4. The principal dimensions and weights of the locomotives exhibited will be clearly seen from the following table as well as from the schematic outline sketches of the various engines exhibited, both tables and illustrations being mostly taken from the *Zeitschrift des Vereins Deutscher Ingenieure* (Figs. 311 to 316). It will be very apparent, from an inspection of both plates and illustrations, that a great many types were represented, but it should be stated at once that as a whole the exhibition gave a correct idea of the types of locomotives which are being built at the present day in

der & Co.





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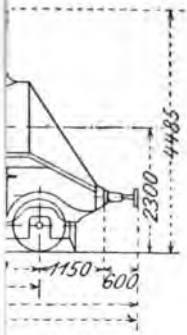
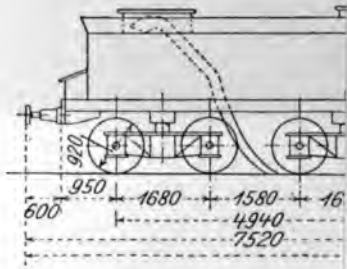
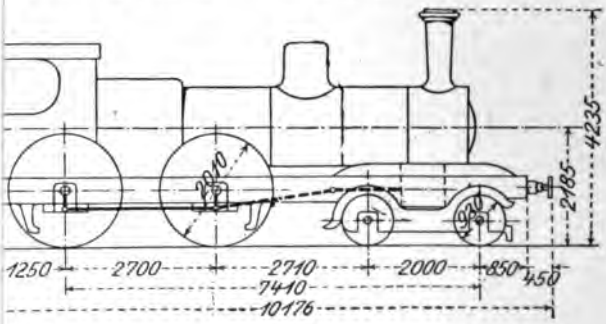
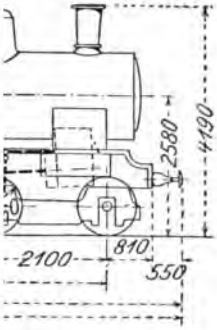




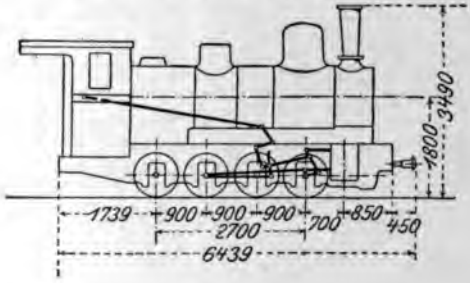
Franz. Westbahn

Bahnwerkst. in Batignolles



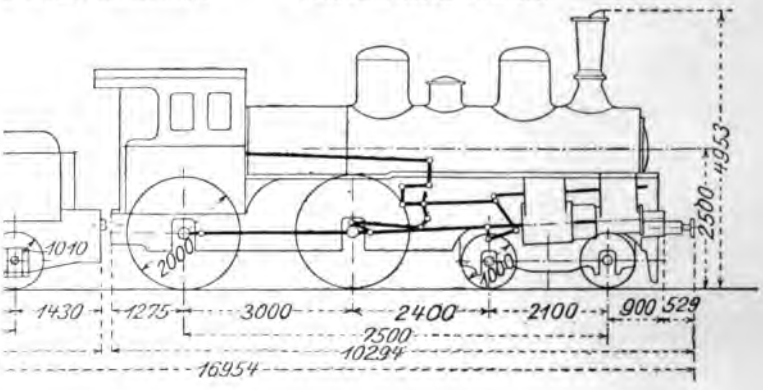


17. Masch.-Fabrik Kolomna

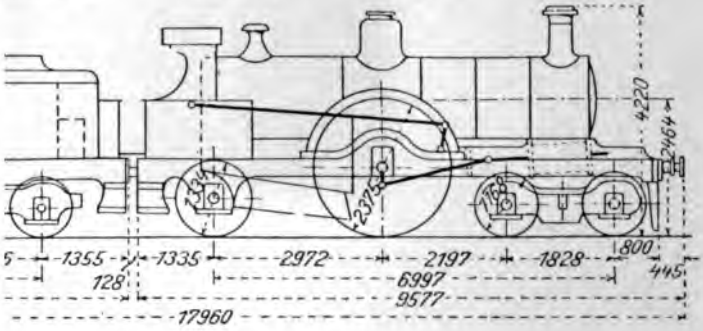


s. Russ. Staatsbahn

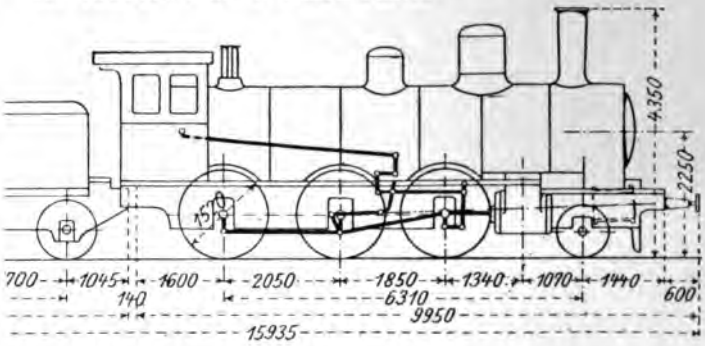
Masch.-Fabrik Poutiloff



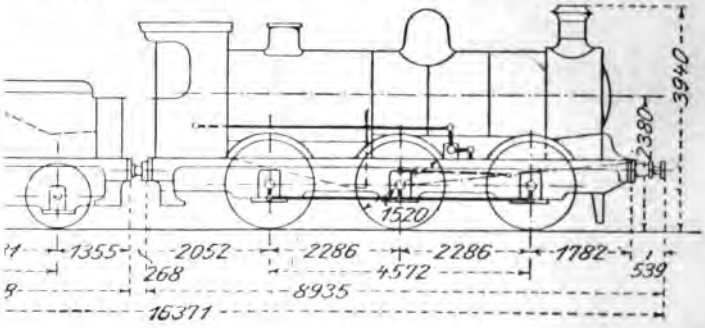
dland R. **Bahnwerkst. in Derby**



29. **Schweiz. Lok.- u. Masch.-Fabrik**

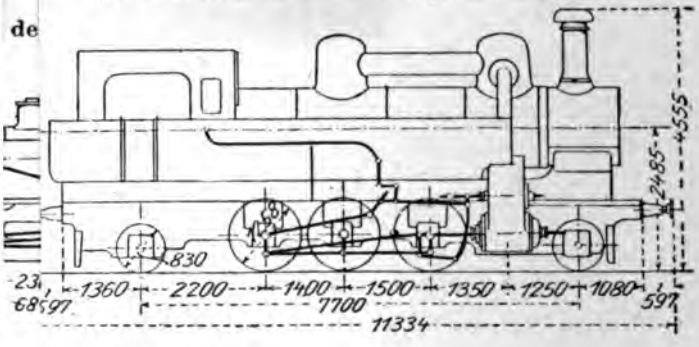


es Forges, Usines et Fonderies, Haine-St. Pierre

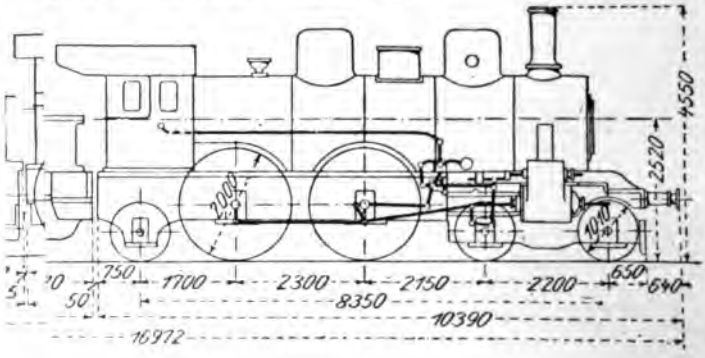


39. Masch.-Fabrik d. Oest.-Ung. Staatseisenb.-G.

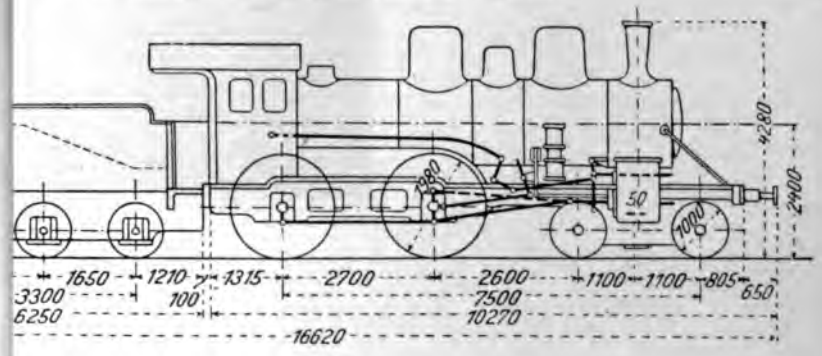
de



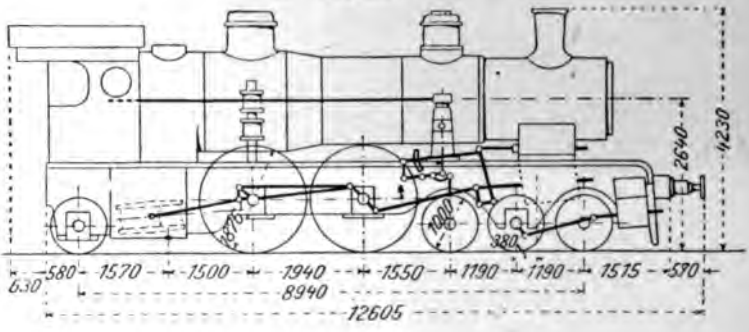
W A.-G. d. Lok.-Fabr. vorm. G. Sigl



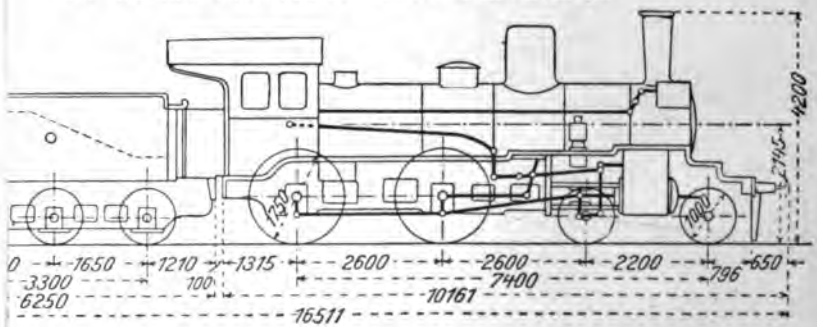
48. Hannov. Masch.-A.-G. vorm. G. Egertorff



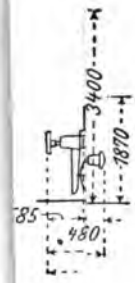
53. Kraufs & Co.



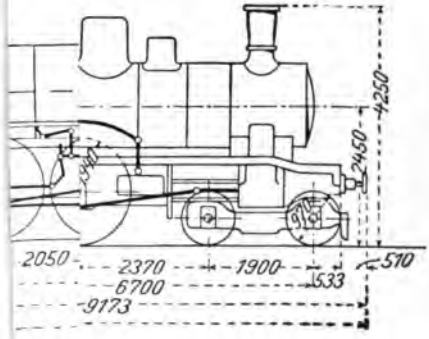
58. Berliner Masch.-A.-G. vorm. L. Schwartzkopff



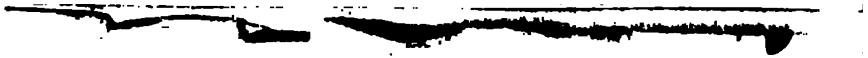
STORM BULL.



. l. Stɔda



nickel-plated couplers and pulleys, [illegible]s and bearings,



the various countries, and not of the present equipment of the various railways. This was especially true of France, Germany, Austria, Hungary, and Switzerland, and to a certain extent also of Russia, which surprised everybody with its exhibit. The design of the locomotives of this last-named country was really original in a great many ways, and although it seemed to the writer that somewhat too much extra finish and bright paint had been put on for exhibition purposes, the workmanship seemed very good. In passing, it might also be noted that Russia exhibited the largest locomotives with the exception of the one shown by Creuzot at Champ de Mars. It was quite surprising that Russia should have made such a good showing in this line, as it must be remembered that the width of the gauge is different in Russia from that in the remainder of Europe, necessitating special axles, and because in several cases it was found necessary to take the locomotives to pieces on account of the difference in the profile of the Russian railways.

The German exhibition was, taken as a whole, perhaps the most instructive of all—14 locomotives, all of different design and made for different purposes. In this connection it might be mentioned that the nine German exhibitors arranged among themselves beforehand what each individual firm was to exhibit, and this for the purpose of showing as large and as good a selection of German locomotives in Paris as possible, in which object they certainly were very successful.

France, naturally enough, showed the largest number of locomotives; but the variety was not as great as in the case of Germany. However, a number of very fine specimens were shown, and the exhibition gave a very excellent idea of the new equipment of the French railways.

The Belgian exhibition was quite a disappointment to most visitors, because the 6 locomotives exhibited were all, with one exception, built after English models, whereas the new equipment of the Belgian railways in general is quite different, this being especially true of the locomotives for heavy passenger service, of which, however, there was only one shown. The workmanship was good, but, as stated, there was nothing new or original in any of the locomotives shown.

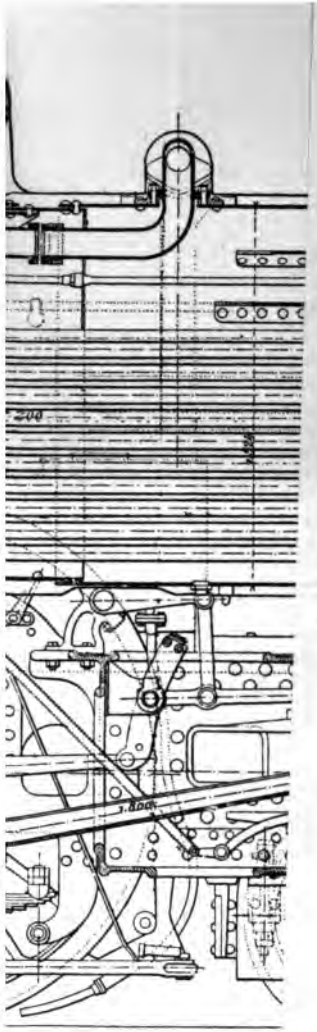
Great Britain exhibited 5 express locomotives—all of them of the purest English type. Nothing further needs to be said about these except that the finish on these engines was altogether overdone; nickel-plated couplers and buffers, polished springs and bearings,

etc., etc., may perhaps impress the ignorant public, but to the engineer it looks more or less like a show.

Switzerland has only one factory for locomotives, but this factory exhibited no less than 5 engines, all of different size and type, and showing both excellent design and workmanship. Everybody who saw these locomotives could not help but admire the taste and neatness shown in the decoration and finish.

A number of the locomotives exhibited at Paris have been selected by the writer for further and more detailed illustration. Some of these have been selected because they represent the best and newest standard in European practice; others, again, because they distinguish themselves by originality of design, going so far even in some instances as to become almost "freaks." In addition to these, the three Baldwin engines shown at Paris are illustrated, although these engines hardly come under either of the above categories. I am indebted to the Baldwin Locomotive Works for the photographs from which these illustrations are taken; the others have been taken from either the London *Engineer* or *Engineering*, to whom the writer desires to express his obligations.

5. The first locomotive illustrated in detail is a four-cylinder compound, made for the Northern Railway of France by the Société Alsacienne de Belfort (Figs. 317 to 321). It is built on the de Glehn system, M. de Glehn being the director of the Société Alsacienne. As has already been pointed out, this style of engine has now become the standard for heavy and fast passenger trains on all the seven railway companies of France. The railway company really exhibited two of these engines, one of which, however, was not at Vincennes, but was used for making experimental runs principally between Paris and Calais. The performances of this latter engine were truly remarkable and have created a great deal of well-deserved attention. The country through which the road runs is not level; on the contrary, there are a number of grades, some of them quite heavy and very long. On a continuous grade of 1 in 125 and 8 miles long this engine pulled a train weighing 300 tons—exclusive of engine and tender—at a speed which never was less than 52.2 miles per hour; another, not quite so heavy grade, 26 miles in length, was begun with a speed of 3 miles per hour; the speed rapidly rose to 40, 50, 60, and 62.5 miles per hour, which latter speed was maintained for the larger part of the grade and to the summit. Hauling a train weighing 405 tons, this engine made 81¾ miles in 79½ minutes; and with 340 tons behind the tender the time was 73 minutes, and with



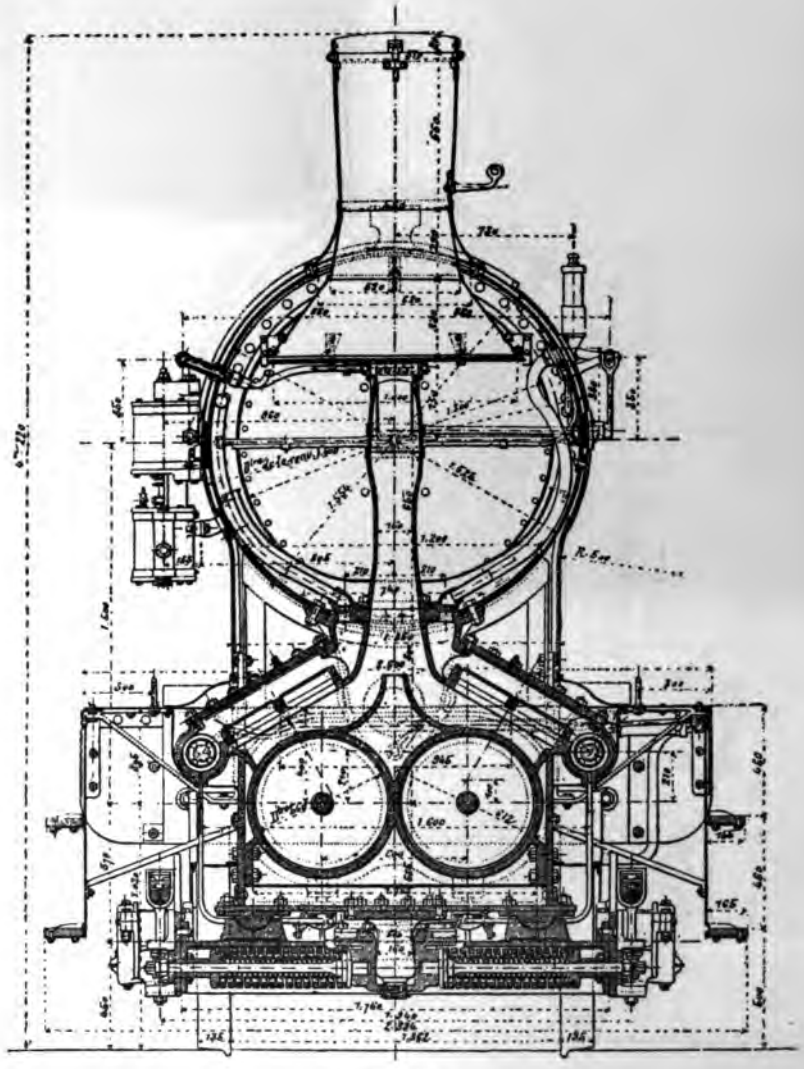


FIG. 319.

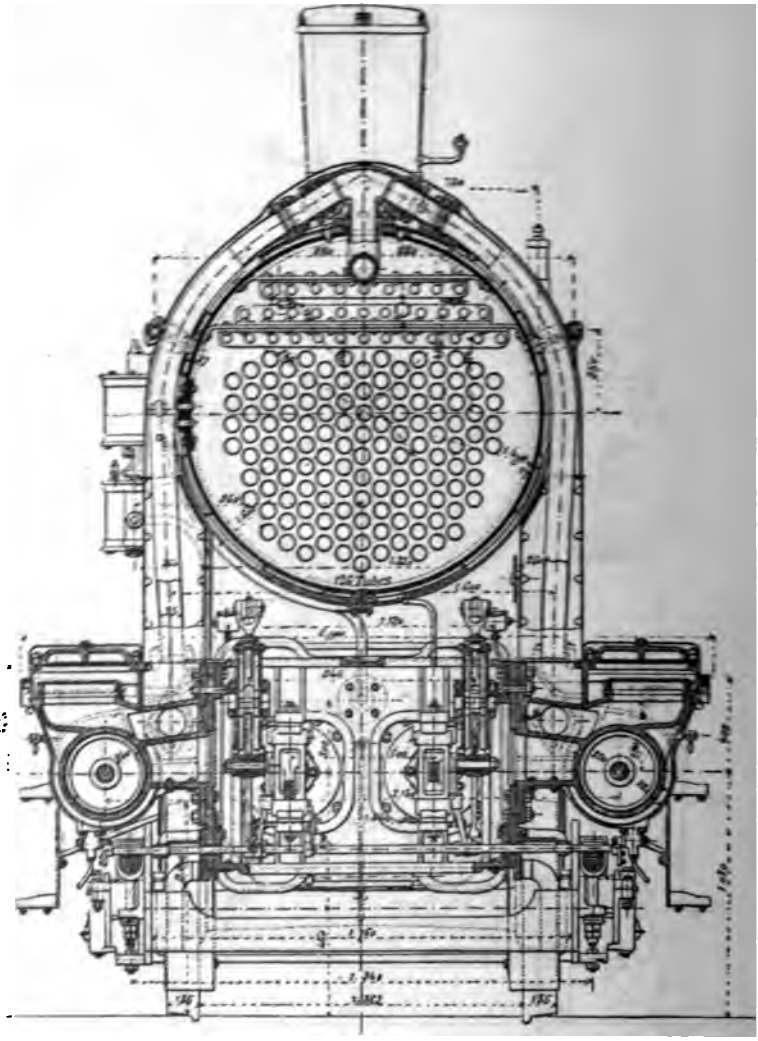


FIG. 320.

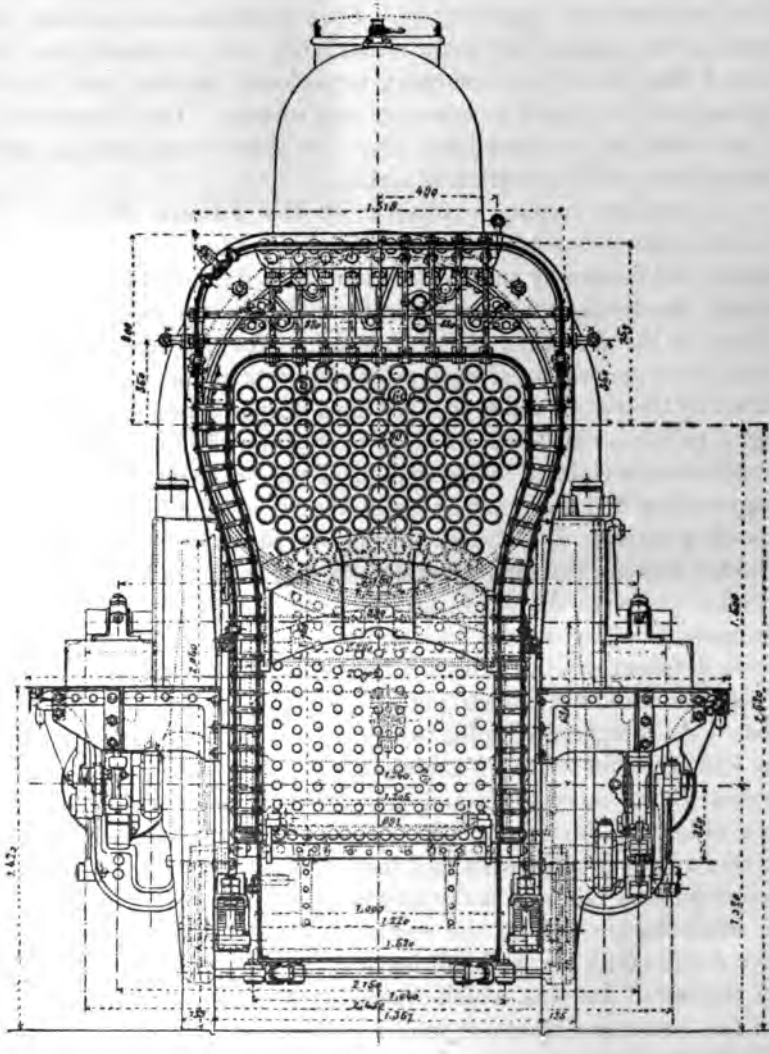


FIG. 321.

253 tons only 71 minutes. A distance of 103¾ miles was passed over in 96 minutes with the last-named weight of train. Again, a train weighing 340 tons was pulled on the level at a speed of 72 miles per hour and continuously. Such performances as these, it seems to the writer, are truly remarkable, and it should also be noticed that the railway company is perfectly satisfied with these engines both in regard to economy and repairs. The illustrations do not need any explanations; there are three cross sections, one longitudinal, and one horizontal section.

6. A similar engine, exhibited by the Eastern Railway of France, is also illustrated by three cross sections and one longitudinal section, and besides by an exterior view (Figs. 322 to 326). As will be seen, the details differ somewhat from those in the locomotive exhibited by the Northern Railway, and it is for this reason and because of the general excellency possessed by this class of engines, as proven by the record made, that two such similar ones are shown. It might, perhaps, not be out of place to mention the fact that one of the advantages claimed by the makers of the de Glehn four-cylinder compounds is that they start so easily, the valve gear being arranged in such a manner that live steam may be sent to the low-pressure cylinder while at the same time the exhaust from the high-pressure cylinder passes to the stack directly. It is also evident that the arrangement of having the high and low pressure cylinders coupled to two different driving axles will contribute to making the engine run easier if the cranks are put at the proper angle towards each other. As compared with the two-cylinder compound, or even with the four cylinder of the Vauclain type, the de Glehn compound necessarily has more parts, and therefore will cost somewhat more than either of the others. But, again, here the manufacturers claimed an advantage in the fact that they do not need to make the various parts as large or heavy as when all the power developed by the steam on one side of the engine shall be transmitted through one rod and crank pin, and still leave them large enough to prevent any heating of the pins, which otherwise, with the now usual heavy and fast passenger trains, is such a common occurrence when the ordinary engines are used. It certainly is a fact that during the extensive experimental running of the engine of the Northern Railway, and with very heavy trains, there was no time lost because of hot pins or bearings.

Before the present type of four-cylinder compounds was adopted by the French Railways a number of years were spent by several of

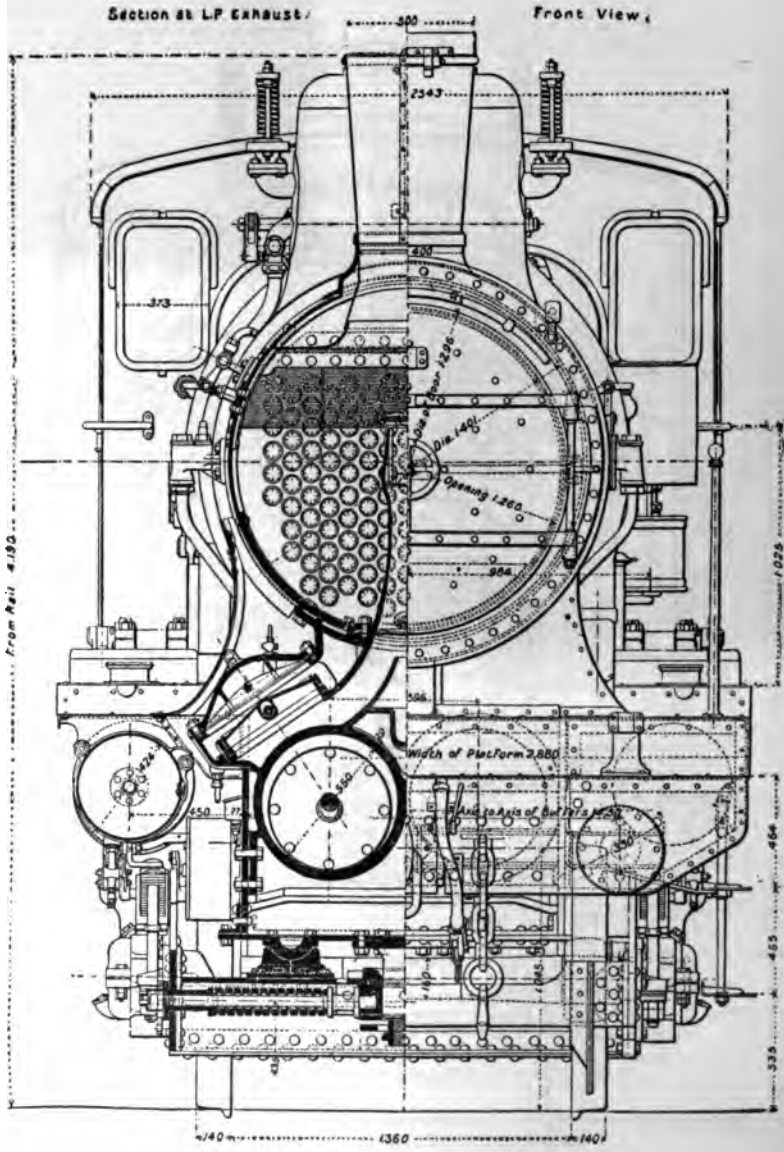

Section at L.P Exhaust
Front View
300
2343
420
373
Dia 1395
Dia 1401
Opening 1260
984
596
Width of Platform 2,880
650
172
1045
140
1360
140
1025
464
465
335
from Rail 4.190

FIG. 324.

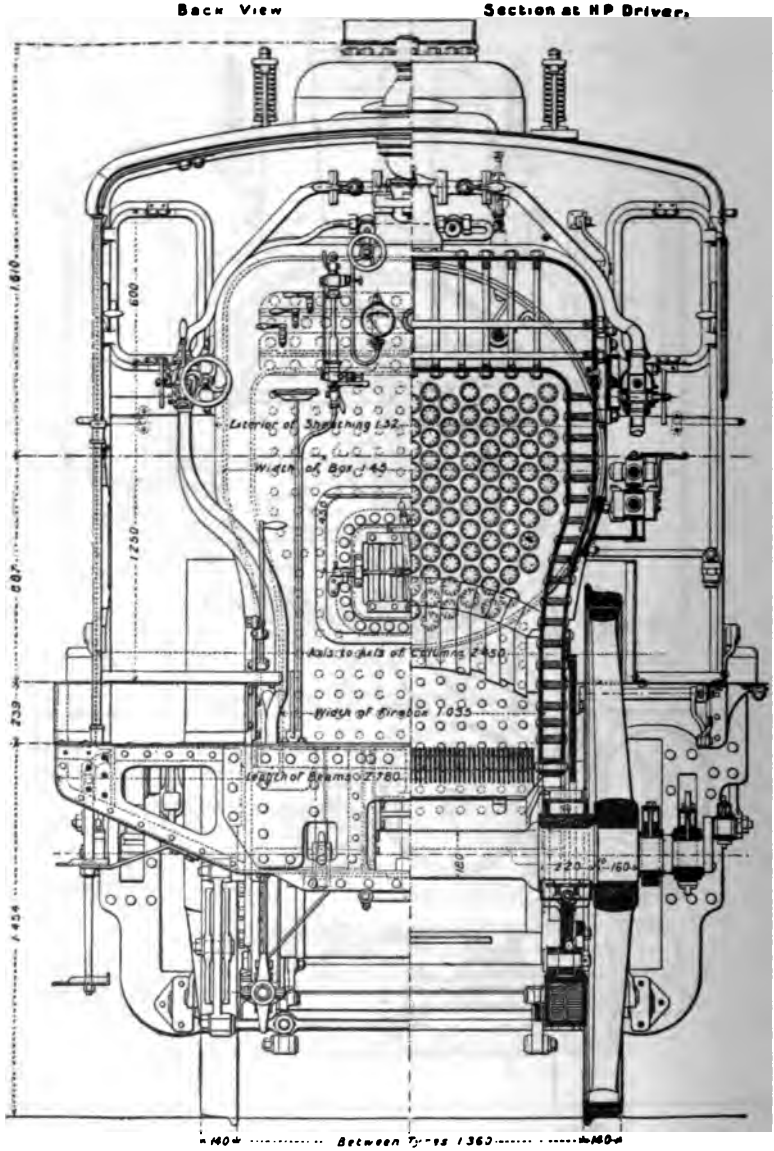

Back View
Section at HP Driver.
Centres of Stretching 1.32
Width of Box 1.45
Axis to Axis of Cylinders 2.450
Width of Firebox 1.035
Length of Beams 2.780
Between Tyres 1.360

FIG. 325.

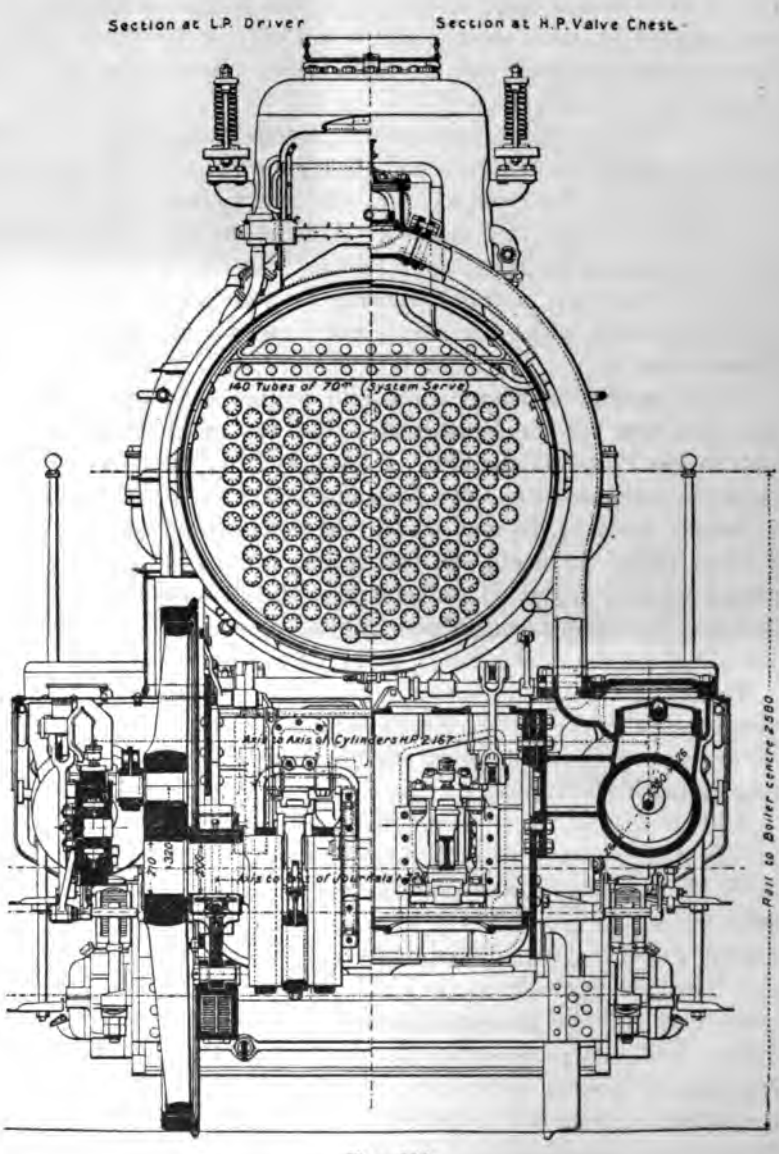

Section at L.P. Driver
Section at H.P. Valve Chest
140 Tubes of 70m/m (System Serve)
Axis to Axis of Cylinders H.P. 2167
Rail to Boiler centre 2580

FIG. 326.

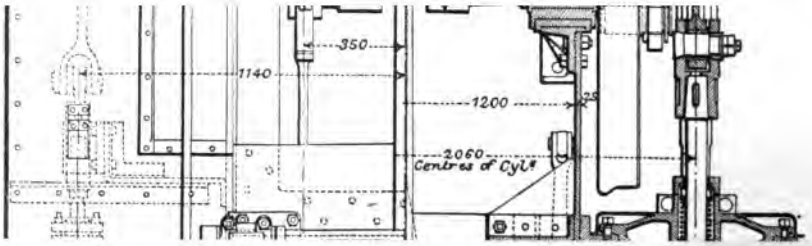
the railways—especially the Northern and Western—in determining by careful and costly experiments which type of engines was best adapted for their service, and it was only on the conclusion of this experimental work that the rapid introduction of the de Glehn locomotive was started.

7. A three-cylinder compound locomotive, made by the Schweitzerische Locomotiven und Maschinen Fabrik at Winterthur, is illustrated by two cross sections, one longitudinal and one horizontal section (Figs. 327 to 330). This locomotive was made for the Jura Simplon Railway, and is in every way a very fine specimen. There is, however, nothing unusual to note about this locomotive, the details, which are very good, being plainly shown by the illustrations.

8. As another standard compound engine—the one made by the same firm for the Northeastern Railway of Switzerland is illustrated in Figs. 331 and 332. It has only two cylinders, and is designed to carry heavy and fast passenger trains up very steep grades. It should, however, be understood that there are no trains in Switzerland which we would call fast trains, whereas, necessarily, the grades are very heavy. This locomotive also shows the same careful design as the other locomotives exhibited by the same firm, and, as stated before, the workmanship could not be any better.

The other engines illustrated all have some original parts which distinguish them from the ordinary engines made, and among them there are several which possess features which may become of great importance in the future.

9. The first of these locomotives which the writer deems of sufficient importance to be illustrated in the *Transactions* of the A. S. M. E. is one made by Borsig, of Berlin. It is shown in three cross sections (Figs. 333 to 335), illustrating principally the superheater, which is the main distinguishing feature of this locomotive, and also an exterior view which shows the large smoke-box made necessary by the superheater which is installed there (Fig. 336). The first cross section is one through the smoke-box and superheater looking backwards; the second is a horizontal section through the smoke-box and superheater near the top, and the third figure is an outside view of the smoke-box, the front having been removed. The locomotive proper is of the Standard Prussian Railway type. The superheater is built according to the Schmidt patent, and consists of a nest of 60 tubes of 1½ inches outside diameter. These are arranged in a cylindrically shaped chamber


350
1140
1200
25
2060
Centres of Cyl.s

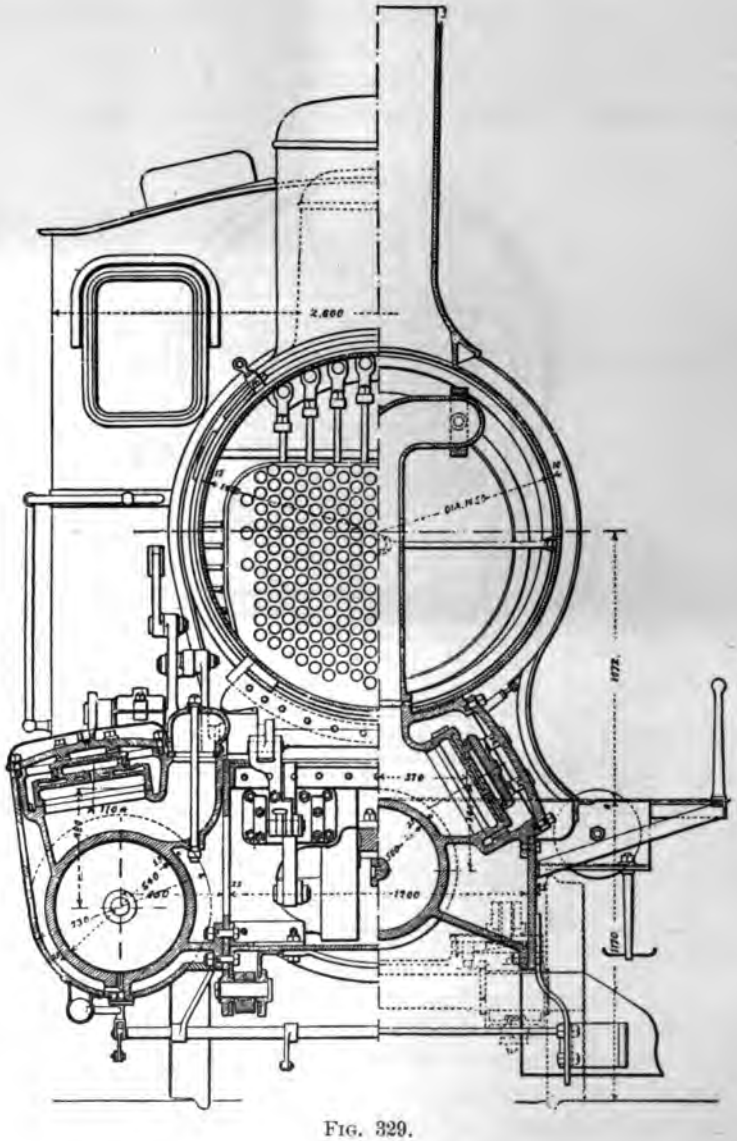


FIG. 329.

surrounding the smoke-box proper. The flue gases used for superheating the steam come through a tube 10 inches in diameter, installed in place of a sufficient number of small tubes at the bottom of the cylindrical boiler. The gases from this tube pass up and around these tubes and from them into the stack. The 10-inch tube serves, of course, to heat the water in the boiler, but the

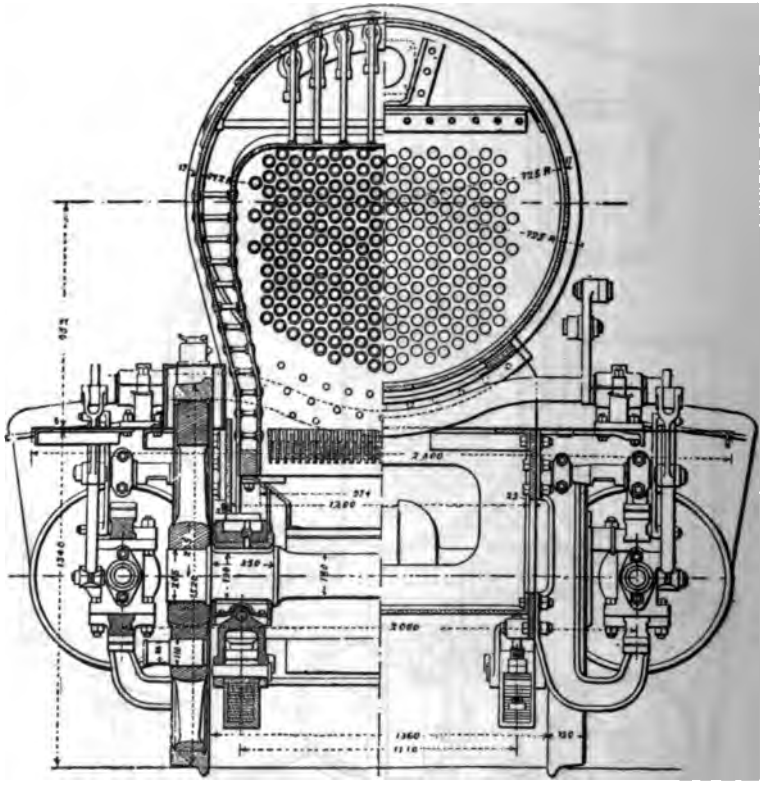


FIG. 330.

diameter being so large the gases arrive at the superheater without having lost very much of the heat. By means of dampers more or less of these gases may be made to pass through the superheater, and besides this regulation by hand, the amount of vacuum due to the blast will also influence this flow. The greater the power developed by the locomotive the greater the vacuum, and, necessarily, also the greater the amount of gases that will come to the superheater. It is stated that this superheater is capable of raising

1
4
5
Diat. 1407
Diat. 1450
1287
430
1,330
2,90

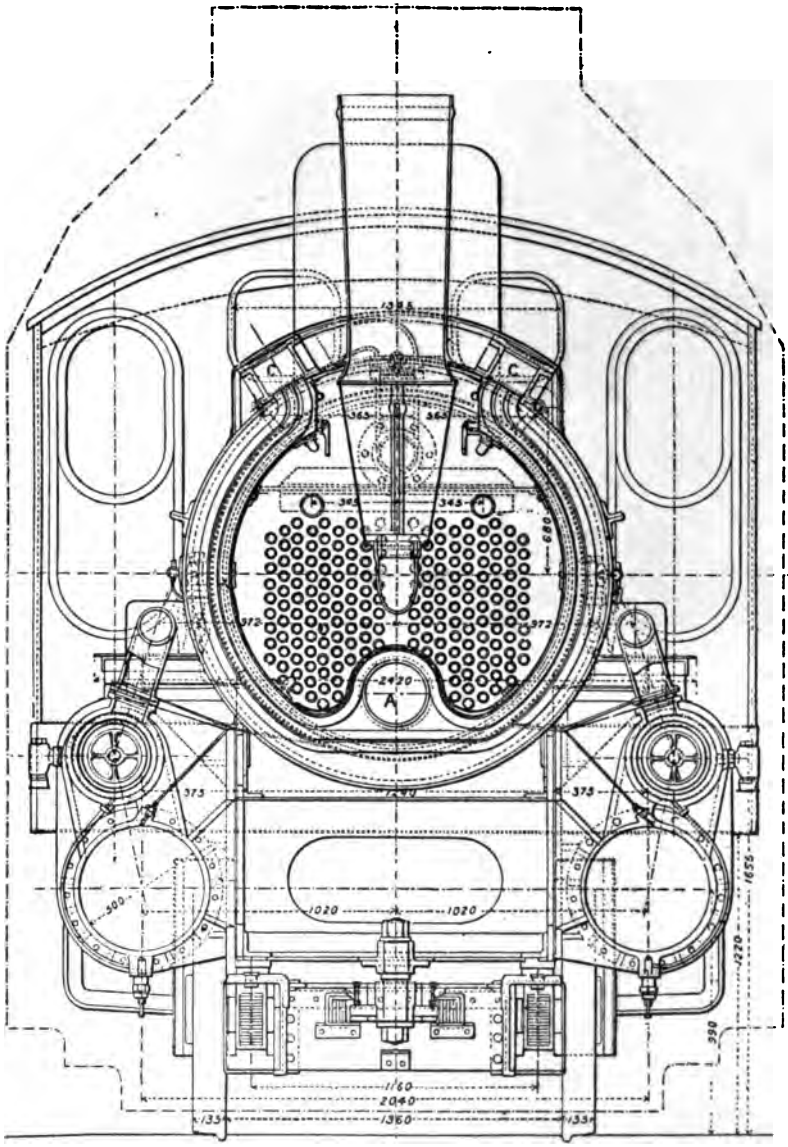

1384
345
345
680
372
372
2420
A
373
373
1020
1020
1655
1270
350
1160
2040
1360
135
135

FIG. 333.

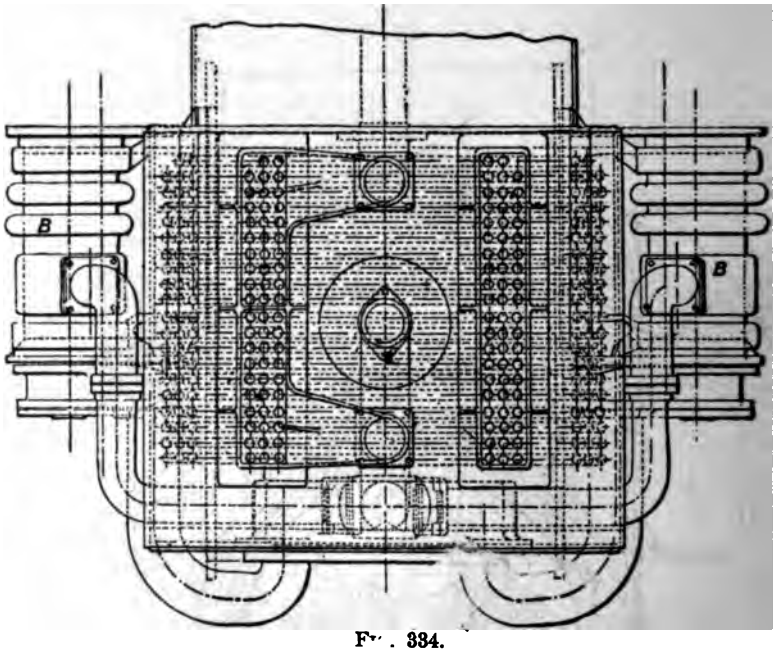


Fig. 334.

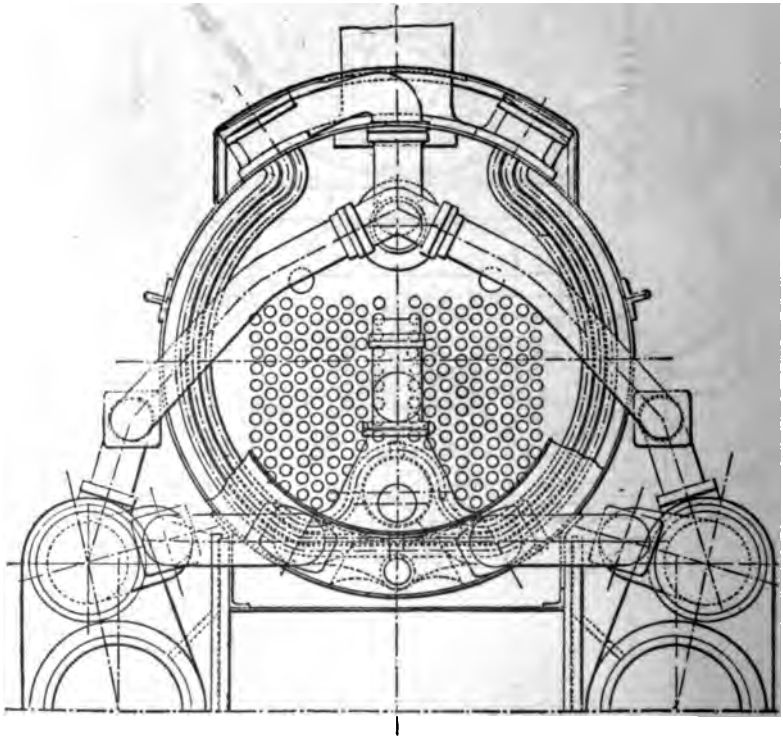


Fig. 335.

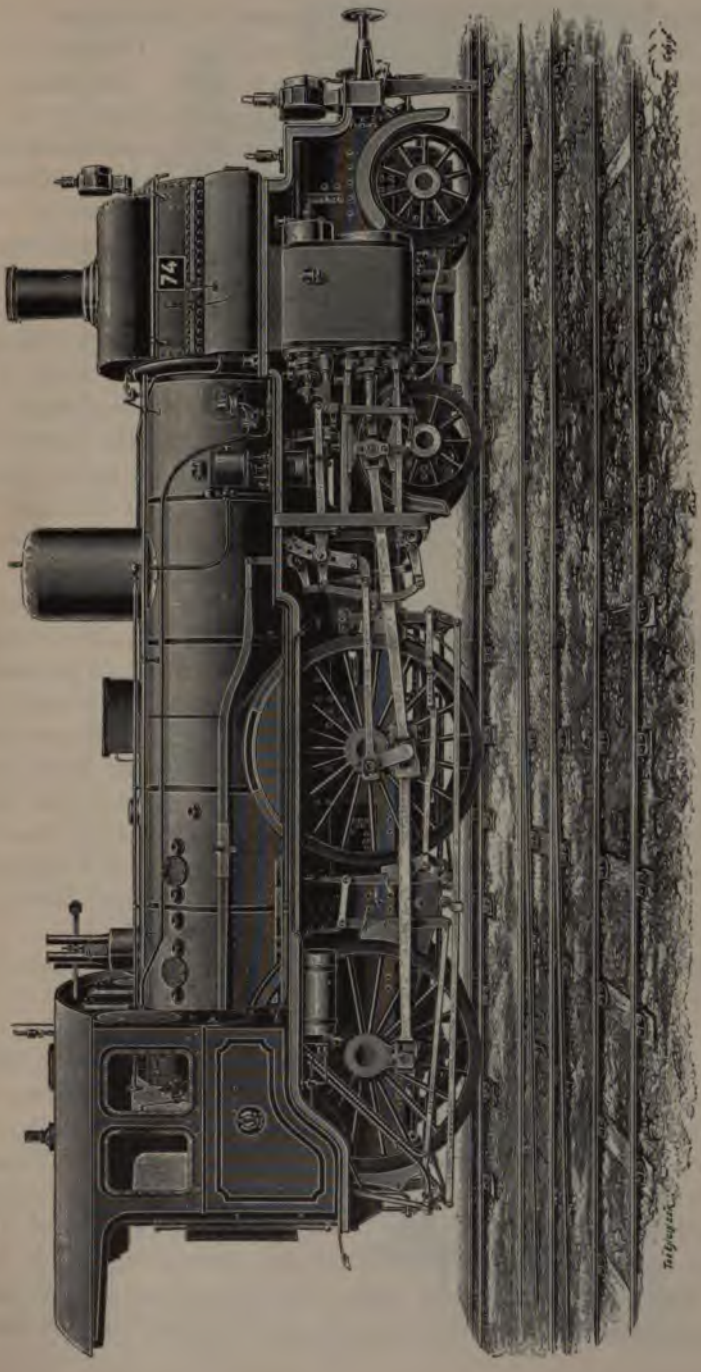


FIG. 836.

the temperature of steam of 176 lbs. pressure to 626 degrees Fahr., which is a superheat of nearly 250 degrees Fahr. Ordinarily the temperature used is only about 570 degrees Fahr. The temperature of the gases is reduced about 1,400 degrees Fahr. by being passed through the superheater. The details of the superheater will be seen upon inspection of the illustrations. It is perhaps sufficient to state that the steam enters the superheater through a header into which the 60 tubes are expanded, this header having a transverse diaphragm, so that the steam must pass through 30 of the tubes over to the other header into which the other ends of the tubes have been expanded, and from this header the steam flows back through the remaining 30 tubes to the first header, but into a portion of it separated from that part of it into which the steam first enters by the diaphragm. The engine exhibited at Paris is the third one made for the Prussian State Railways, the first two having been made by the Vulcan Works of Stettin. The results obtained by the first two locomotives provided with superheaters were very satisfactory it seems, and this third one was of course designed in such a manner as to overcome such small difficulties as had been found in the first two experimental engines. The makers expect to realize an increase in the boiler horse-power of about 33 per cent., and without material increase of size, 25 per cent. saving in coal and 33 per cent. decrease in the consumption of water. The locomotive exhibited was an ordinary twin engine, but there is no doubt that the saving for a compound would be equally as great. The only question would be, assuming a great gain in efficiency of the ordinary twin engine due to the superheating, whether it would pay to use compound locomotives with the complications and disadvantages connected with this class of engines.

It is hardly necessary to state that the engine in all respects was up to the high standard maintained by the firm of Borsig.

10. The four-cylinder compound exhibited by Maffei, of Munich, belongs to the Mallet type of compounds (Figs. 337 to 340). The peculiarity of this type consists in the fact that the axles are divided into two groups, each group being coupled to two cylinders. In the locomotive exhibited the rear group was rigid with the boiler and was driven by the high-pressure cylinders, whereas the forward group was flexible and was driven by the low-pressure cylinders. The Mallet system was originally designed for narrow-gauge roads, and later was used for mountain roads with ordinary gauge but with curves of small radii; but this locomotive had been built for the Bava-

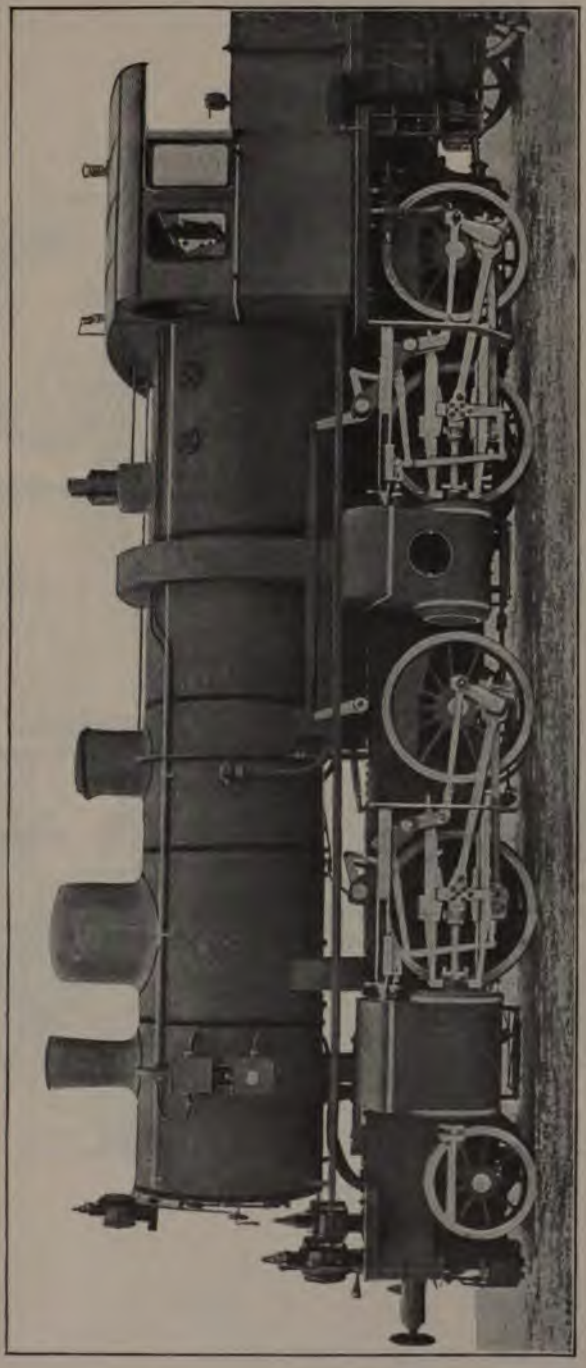


FIG. 337.

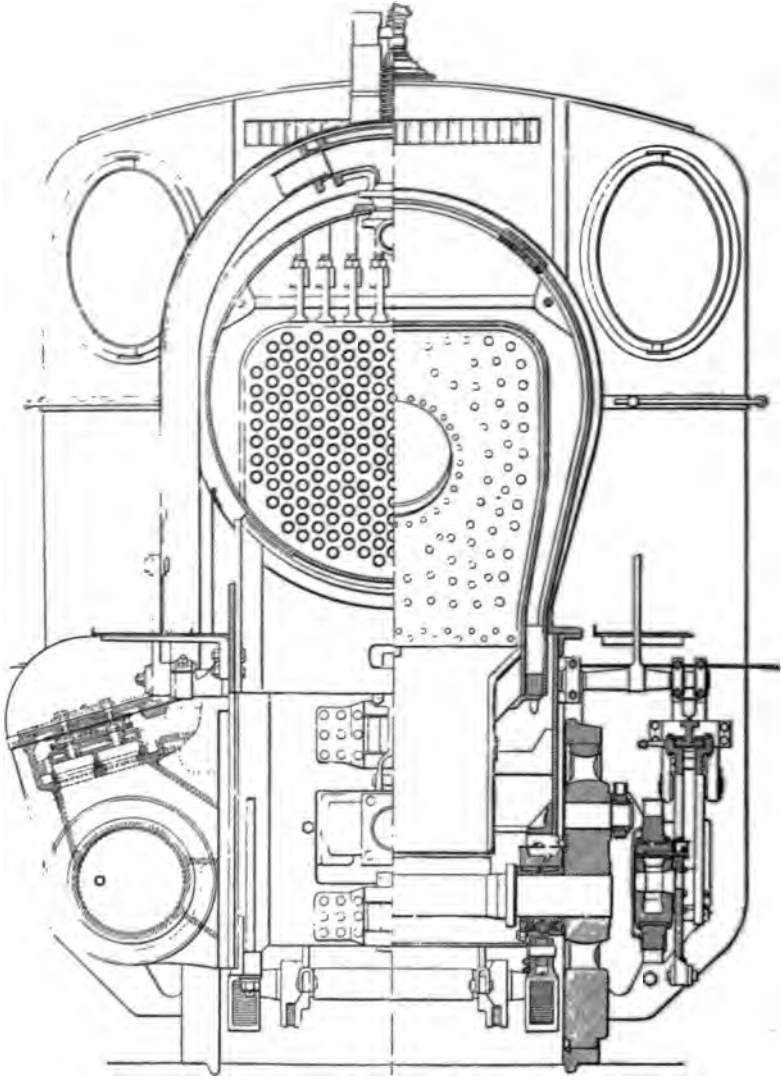


FIG. 338.

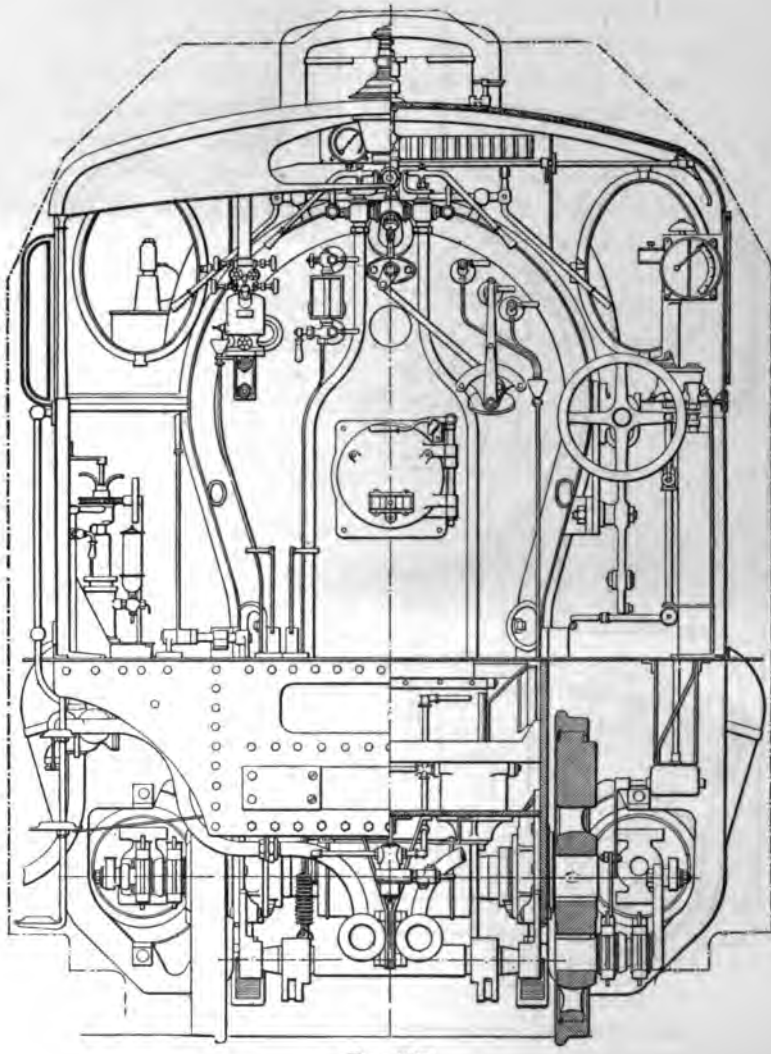


FIG. 339.

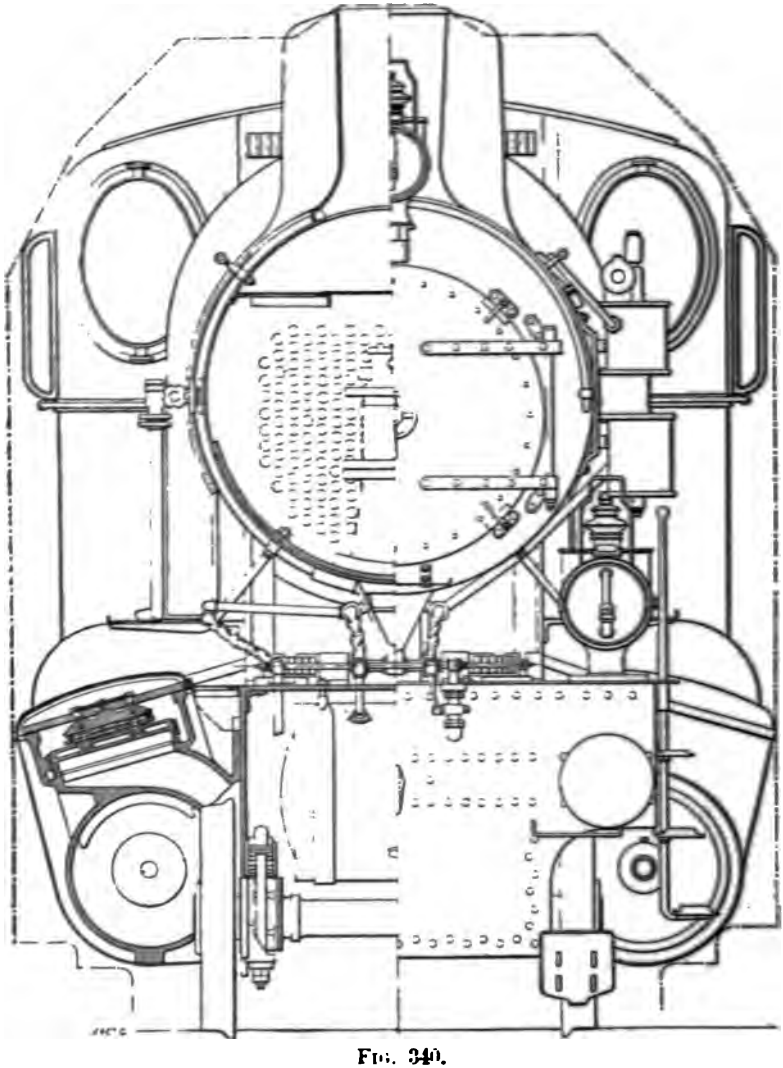


FIG. 340.

rian State Railways, it being the opinion of the makers that this type of engine having proved so very efficient on mountain roads, there was no reason why it should not be just as efficient for ordinary railways. The locomotive is illustrated by several cross sections, one longitudinal, and one horizontal section. The details of the engine will be very plainly seen from these illustrations, and the only thing calling for comment are the peculiarities connected with the subdivision of the axles and wheels into two groups. Necessarily, the steam connection between the high and low pressure cylinders must be a flexible one; this connection forms a receiver and is placed in the longitudinal axis of the frame. At its forward end it is fitted with a corrugated and elastic sleeve which accommodates itself to the deflections of the track. The forward portion of the boiler is supported by a frame which is fixed to the rear end of the frame by means of a vertical hinge joint between the two groups of axles. The boiler is fixed rigidly to the rear frame, and in order to prevent a too great mobility of the forward frame a pair of horizontal springs is installed beneath the smoke-box, which springs bear against the support of the smoke-box. These details will be seen quite plainly from the illustrations. It should also be stated that there are now several similar engines working very satisfactorily on the Bavarian State Railways.

11. One of the great curiosities of the Paris Exhibition was, in the opinion of the writer, the huge locomotive exhibited by Schneider & Cie. in their pavilion on the Champ de Mars. It was, taking it altogether, the most powerful engine shown, as can be readily seen from the table which contains the principal dimensions, weights, etc., of the locomotives shown (Figs. 341 to 346). It was built as an experimental engine, and before the opening of the exposition a large number of experimental runs were made. It was designed to move trains weighing 220 tons behind the tender at a speed of 120 kilometers, or about 75 miles, per hour on the level. The energy developed amounts to from 1,800 to 2,000 horse-power, which certainly is a very formidable amount. It has made more than 100 miles per hour, but as such speeds are not allowed in France, the maximum allowed on the very best roadbeds in France being but 74.6 miles, a speed of 100 miles has at present no practical value in that country. A special permission was granted for the particular run when this speed was reached. One of the features of the locomotives, and which is not apparent to the ordinary onlooker, is that boiler plates, rivets, tie bars, angles, connecting roads, and cranks are

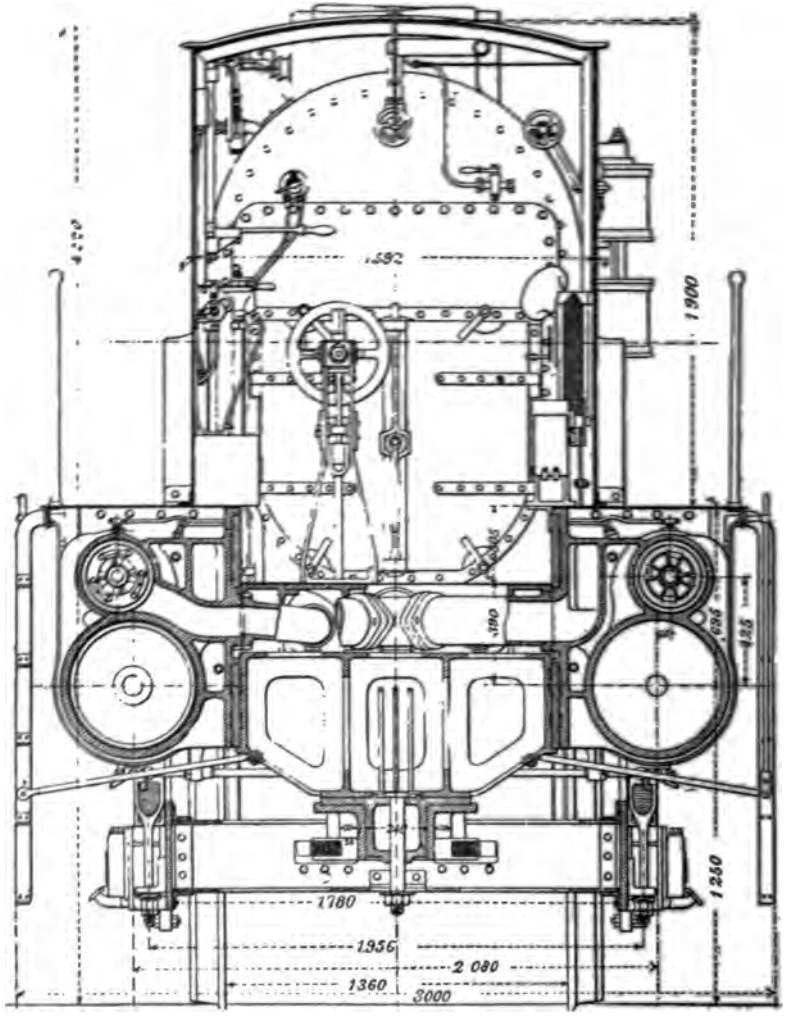


FIG. 341.

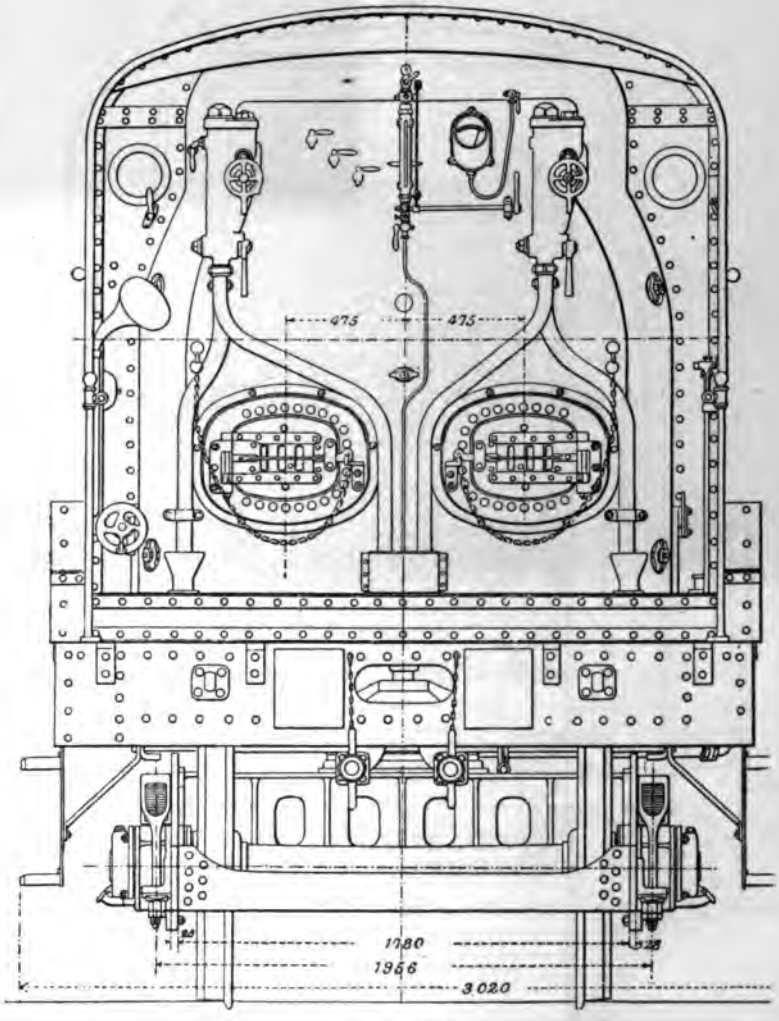


FIG. 342.

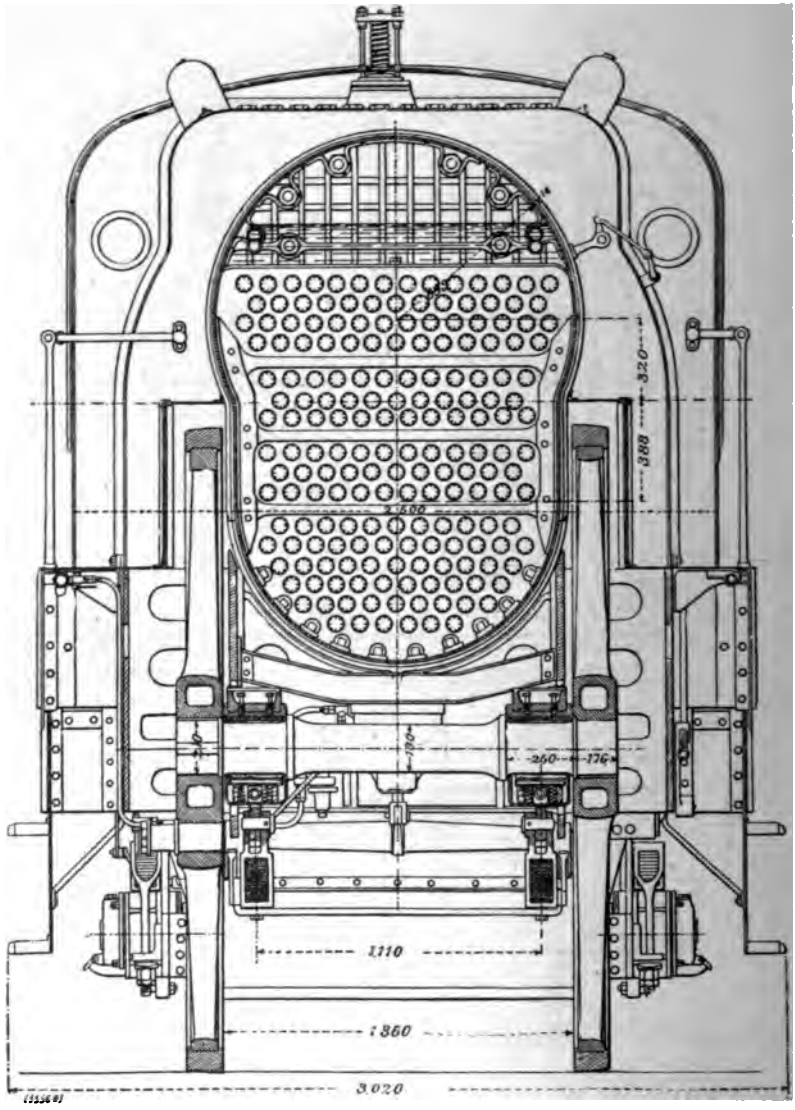


FIG. 243.

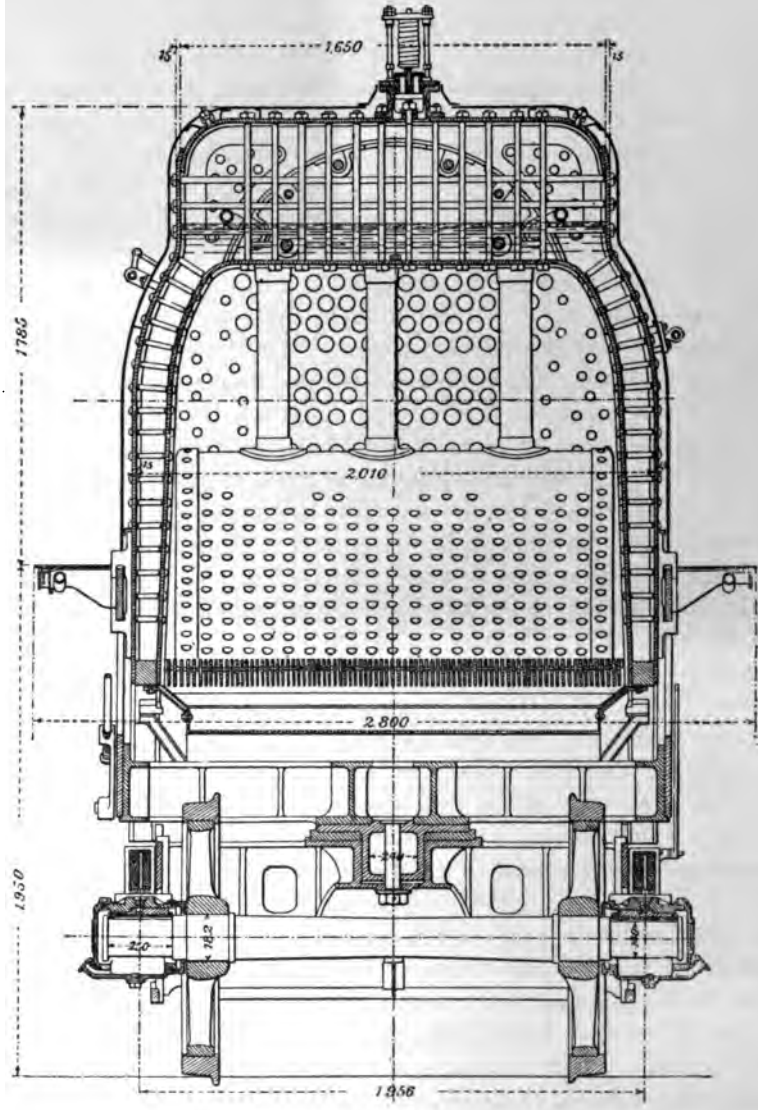


FIG. 344.

all made of nickel steel, the large driving wheels of cast steel. The breaking strength of the steel used for the boiler plates is from 70,000 to 77,000 pounds per square inch, and that of the connecting rods and cranks is from 84,000 to 90,000 pounds per square inch. The illustrations, especially the external view of this locomotive, will give some idea how queerly it looks. It will at once be noticed that there are two cabs, one in front for the engineer, and one in the rear for the fireman. The advantages to be derived from having the engineer in front are very apparent—freedom of outlook, and this not alone because the engine does not obstruct the view, but also because smoke and steam do not surround the cab. The engineer is also close to the cylinders and valve gear—the parts in which he is especially interested. That there are disadvantages in separating the engineer from the fireman is very certain, and they are so apparent that they need not be pointed out. It will be noticed that the front of the cab has been given such a shape as to reduce the resistance of the air as much as possible. Another peculiarity of this locomotive is that it has not less than 14 wheels, of which 4 are driving wheels, 4 are in a truck under the smoke-box, and the other 6 in a truck under the rear part of the locomotive. This arrangement allows, of course, a very wide fire-box, like that on our Atlantic type engine. The boiler itself is of a very peculiar shape, presumably to gain heating surface without making it too wide. Both the grate and heating surface of this locomotive are enormous—respectively 50 and 3,200 square feet—and it can easily be believed that the boiler was ample to produce the necessary amount of steam for the high speeds obtained as well as for the 1,800 or 2,000 horse-power developed. The diameters of the driving wheels are 98½ inches—2½ inches more than 8 feet. Even the two-wheel coupled English express engine had only 93½-inch driving wheels, the Creuzot engine having four wheels of 98½ inches diameter. The enormous size of this locomotive can also be seen from the length of its wheel base, which was equal to 40.4 feet.

It is perhaps not likely that this locomotive will find imitators in all its details. But there is so much originality in its design and in the material used that one should not be surprised to see some of the novelties adopted in future practice. It ought to be unnecessary to state that the workmanship and finish of this engine, as well as of the others shown by Schneider & Cie., were of the very best.

12. A locomotive shown by Krauss & Co., of Munich (Fig. 347), belongs, perhaps, properly to the "freaks" of the exhibition. It is

500

the one which was provided with two auxiliary cylinders coupled to two auxiliary wheels. The engine was otherwise a two-cylinder compound with four driving wheels. The auxiliary cylinders are, as will be seen from the illustrations, placed to the very front, and the auxiliary wheels are placed between the wheels of the front truck. These auxiliary wheels when not in use are held about 1¼ inches above the rail by means of coiled springs. It is only when steam is admitted to the auxiliary cylinders that at the same time steam is let into two small cylinders with pistons, which latter, by means of various levers, overcome the tension of the springs and press the wheels against the rails. The object sought by the manufacturers by the introduction of these auxiliary cylinders is to be able to transform a locomotive with four driving wheels into one with six whenever desired, and without having to meet the difficulties of design which a six-coupled engine presents. According to the makers, this enables them to have a wider fire-box than if there were to be six driving wheels. But it will, of course, be noticed at once that the auxiliary driving wheels have a very small diameter, and to this objection the makers reply by stating that the auxiliary gear will only be used on heavy grades and at comparatively slow speeds, and for short periods of time. This seems like a reasonable argument, as there is no doubt that both the maximum power and weight on driving wheels are required under those circumstances. Of course it is very questionable, in the opinion of the writer, whether this additional complication is justified by the results obtained. In fairness to the manufacturers it ought to be stated that several engines of similar construction have been in use on the Bavarian Railways for a couple of years and seem to have given excellent satisfaction. It certainly has been proven that the auxiliary driving gear may be put into service at speeds exceeding 40 miles per hour and without injury to any of the working parts, and that they show but little wear.

13. Another "freak" of the exposition was the loc otive exhibited by the Mediterranean Railway of Italy. It v a compound tank engine, which, however, was provided with a ider in the shape of a cylindrical tank for water, the locomotive i lf carrying the coal (Fig. 348). As will be seen from the ill on, t is a large cab, which is wedge-shaped to reduce the r air, and this engine running with the slack behind, so that t i- neer in his cab is at the head of the train. The writer l able to get a satisfactory explanation why the makers

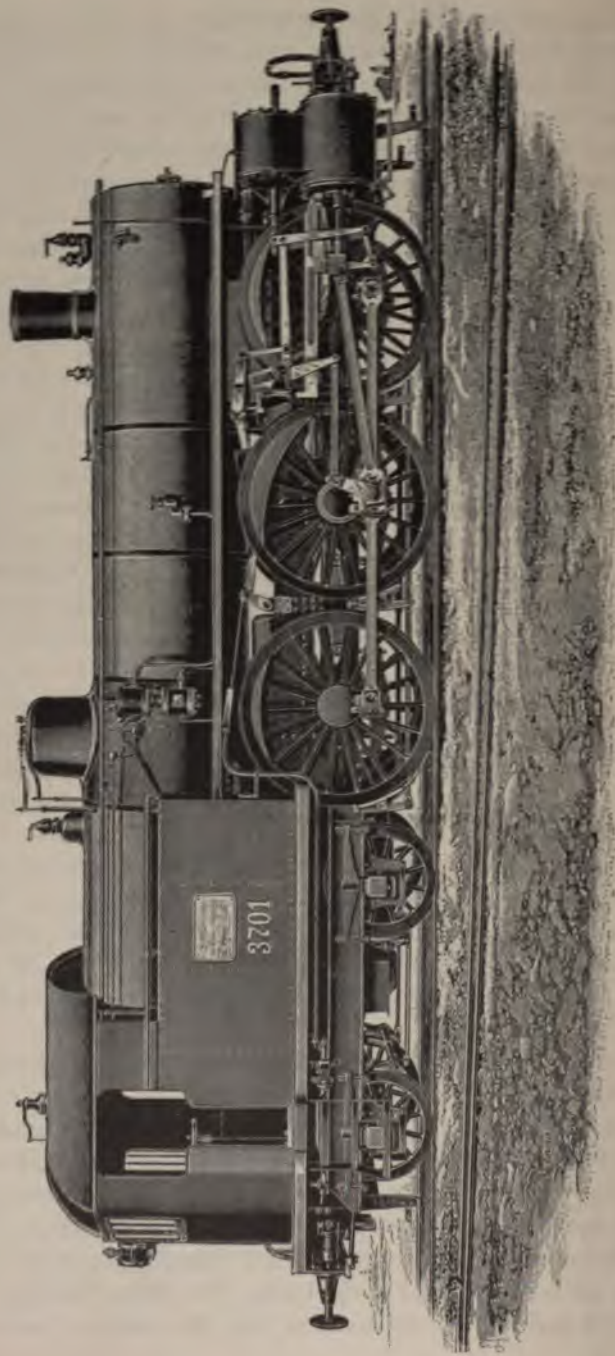


Fig. 343.

necessary to arrange the engine in such a manner that it should run with its hind end foremost, but some of the details of the engine were very good, and the valve gear was quite original. However, they did not seem to have enough merit to warrant a full description. Only the exterior view of the engine is given.

14. Although, as stated earlier in this paper, the engines exhibited by the Baldwin Works did not seem to create a very favorable opinion among European engineers, it seems but simple justice to the firm that in a paper describing the locomotive exhibits at the Paris Exhibition, the only American locomotives shown (Figs. 349 to 355) should find a representation among those illustrated in the paper. Notwithstanding the many harsh things stated in the European technical papers about these engines, we know the excellency of these locomotives, as proven by the daily service of thousands of them on our railways. We have a right to assume that the criticisms expressed are to a great extent due to the successful competition of the Baldwin locomotives on the European market in the last few years. The dimensions and weights of the locomotives exhibited by the Baldwin Locomotive Works are found in the general table. It is unnecessary to describe them, as they are too familiar to the members of this Society to need any description. Only in minor details did these locomotives differ from those made by the firm for American railways, the ones exhibited being made for France and Great Britain.

		Exhibitor.	Manufacturer.	Railway.	Description of Locomotive.	Size of Cylinder. Diam.	Stroke.	Diameter of Driving Wheels.	Total Wheel Base.	Steam Pressure.	Grate Area.	Heating Surface.	Weight on Drivers.	Weight of Engine in Service.	Weight of Tender in Service.
						in.	in.	in.	sq. ft.	lbs.	sq. ft.	sq. ft.	tons.	tons.	tons.
France.	a	Schneider & Co., Creuzot.			Express locomotive with two driving axles, five other axles; tender with five axles.	20	27½	98½	40.4	220	50.38	3,203.3	35.3	88.7	64.0
	1	Southern Ry. of France.	Schneider & Co., Creuzot.	Southern Ry. of France.	Compound freight locomotive with three driving axles; one other axle.	17½ 26½	25½	63½	21.8	220	23.13	1,895.9	45.7	58.5	
	2	Southern Ry. of France	Schneider & Co., Creuzot.	Southern Ry. of France.	Compound express locomotive with four cylinders, two driving axles, two other axles; tender with three axles.	13½ 21½	25½	84	24.8	206	26.47	1,950.8	36.3	50.4	39.2
	3	Southern Ry. of France.	Société Alsacienne, Belfort.	Southern Ry. of France.	Compound passenger locomotive with four cylinders, three driving axles, two other axles; tender with two axles.	13½ 21½	25½	69	25.1	206	26.47	1,950.8	46.0	63.3	26.8
	4	Fives Lille Co., France.		Eastern Ry., China.	Compound freight locomotive with four driving axles, one other axle; tender with four axles.	20½ 29½	25½	49	22.3	176	26.68	1,737.7	61.7	71.8	55.2
	5	State Rys. of France.	Société Franco-Belge, Raisnes.	State Railways of France.	Tank locomotive with two driving axles; two other axles	11½	15½	52	15.2	176	10.76	406.7	22.0	36.3	
	6	State Rys. of France.	Schneider & Co., Creuzot.	State Railways of France.	Express locomotive with two driving axles, two other axles; tender with two axles.	17½	25½	79½	23.9	206	21.52	1,711.2	33.0	56.1	32.6
	7	State Ry. of France.	Baldwin Locomotive Works, Philadelphia.	State Ry. of France.	Compound express locomotive with four cylinders (Vauclain), two driving axles, two other axles; tender with four axles	13 22	26	84½	23.6	220	25.58	1,892.6	34.9	58.0	39.2
	8	Société Nouvelle des Etabs. Décauville aîné, Paris.		Narrow Gauge Ry., Vendée.	Tank locomotive with three driving axles; for narrow gauge, 39⅜ in.	9	14½	33	5.94	220	6.09	301.3	19.1	19.1	
	9	Northern Ry. of France.	Société Alsacienne, Belfort.	Northern Ry. of France.	Compound express locomotive with four cylinders, two driving axles, three other axles; tender with three axles.	13½ 22	25½	80	27.1	220	29.47	2,243.5	36.4	60.3	50.1
	10	Western Ry. of France.	Schneider & Co., Creuzot.	Western Ry. of France.	Tank locomotive, three driving axles, two others.	18½	23½	59½	25.9	176	19.37	1,417.1	48.4	64.8	
	11	Western Ry. of France.	Locom. Wks. of Batignolles.	Western Ry. of France.	Express locomotive with two driving axles, two other axles.	18½	26	79	24.5	169	19.15	1,318.1	31.5	50.8	
	12	Western Ry. of France.	Locom. Wks. of Sotteville.	Western Ry. of France.	Compound express locomotive with four cylinders, two driving axles, two other axles	13½ 20½	25½	79	24.4	206	25.82	1,438.6	34.8	55.0	
	13	Société de Construction de Batignolles.		Paris-Lyon Railway.	Compound express locomotive with four cylinders, two driving axles, two other axles	13½ 21½	24½	74½	23.9	220	26.15	2,089.0	33.9	61.1	
	14	L. Corpet and L. Louvet, Paris.		?	Tank locomotive with three driving axles; for narrow gauge, 39⅜ in.	12	17½	36	6.73	184	7.87	407.1	24.6	24.6	
	15	Paris-Orléan Ry.	Soc. Française de Constr. méc. (Cail), Paris.	Paris-Orléan Ry.	Compound express locomotive with four cylinders, two driving axles, two other axles; tender with three axles.	13½ 21½	25½	84	24.75	220	26.47	2,075.6	36.9	60.5	42.3
	16	Eastern Ry., France.	Locomotive Works at Epernay.	Eastern Ry., France.	Compound express locomotive with four cylinders, two driving axles, two other axles; tender with three axles.	13½ 21½	26	80½	23.9	220	27.11	2,238.7	37.5	63.8	48.7

Russia.	17	Maschienen Fabrik, Kolomna.		Narrow Gauge Ry., Russia.	Freight locomotive with four driving axles; for narrow gauge, 30 in.	14	11½	29½	8.9	176	12.37	538.0	23.1	23.1	
	18	Maschienen Fabrik, Kolomna.		South Eastern Ry., Russia.	Compound express locomotive with three driving axles, two other axles; no tender.	19½ / 28¾	25½	72	26.5	169	23.13	1,491.3	43.7	67.2	
	19	Moskau-Kasan Railway, Brjänsk.		Moskau-Kasan Ry.	Compound freight locomotive (system Mallet), six driving axles; tender with four axles; for naphtha.	18½ / 28	25½	48	27.1	176	26.36	1,937.3	89.9	89.9	53.3
	20	State Rys. of Russia.	Pontiloff, St. Petersburg.	Russian State Rys.	Compound freight locomotive with four driving axles; tender with three axles.	19½ / 28¾	25½	47	12.8	169	10.91	1,490.2	56.3	56.3	38.5
	21	State Rys. of Russia.	Pontiloff, St. Petersburg.	Russian State Rys.	Tandem compound express locomotive, four cylinders, two driving axles, two other axles; tender with three axles.	14½ / 21½	24	78¼	24.8	191	28.19	1,449.3	33.1	62.2	38.5
United States.	22	Baldwin Locomotive Works, Philadelphia.		Great Northern Railway, Great Britain.	Freight locomotive with three driving axles, one other axle; tender with four axles.	18	24	61½	22.8	180	16.67	1,380.0	42.8	50.3	47.0
	23	Baldwin Locomotive Works, Philadelphia.		State Ry. of France.	Express locomotive with two driving axles, three other axles; tender with four axles.	17½	26	84½	26.8	220	35.0	2,095.8	35.9	69.4	39.2
Great Britain.	24	London & North Western Ry.; Crewe.		London & N. W. Ry.	Compound express locomotive with four cylinders, two driving axles, two other axles; tender with three axles.	15 / 20½	24	85	23.3	206	20.44	1,232.0	40.3	61.4	29.8
	25	Midland Railway, Derby.		Midland Ry.	Express locomotive with one driving axle, three other axles; tender with four axles.	19½	26	93½	23.1	185	24.43	1,104.0	20.7	56.1	54.9
	26	Neilson, Reid & Co., Glasgow.		Central Ry. of Holland.	Express locomotive with two driving axles, two other axles; tender with three axles.	18	26	84½	52.6	150	23.03	1,440.8	31.3	51.0	40.5
	27	Great Eastern Railway, Stratford.		Great Eastern Ry.	Express locomotive with two driving axles, two other axles; tender with three axles.	19	26	84	23.6	186	21.3	1,449.4	37.0	55.9	39.2
	28	North Eastern Railway, Gateshead.		North Eastern Ry.	Express locomotive with three driving axles, two other axles; tender with three axles.	20	26	73½	26.2	206	22.9	1,614.0	53.4	70.0	42.7
Switzerland.	29	Schweitzerische Locomotiv und Maschienen Fabrik, Winterthur.		Jura Simplon Ry.	Compound passenger locomotive with three cylinders, three driving axles, one other axle; tender with three axles.	(1) 19½ / (2) 21½	23½	60	20.8	206	24.75	1,509.6	49.6	61.0	30.9
	30	Schweitzerische Locomotiv und Maschienen Fabrik, Winterthur.		Central Ry. of Switzerland.	Compound express locomotive with four cylinders, with two driving axles, two other axles; tender with three axles.	13½ / 20	23½	68	23.1	206	23.67	1,404.2	33.0	53.1	33.0
	31	Schweitzerische Locomotiv und Maschienen Fabrik, Winterthur.		Street Ry., Lyon.	Street railway locomotive with three driving axles; for narrow gauge, 39⅜ in.	9½	13½	32	5.94	206	5.6	280.8	18.7	18.7	
	32	Schweitzerische Locomotiv und Maschienen Fabrik, Winterthur.		Abyssinian Railways.	Locomotive with three driving axles, one other axle; tender with four axles; for narrow gauge, 39⅜ in.	14½	21½	48	16.8	176	10.76	757.5	24.8	39.7	39.7
	33	Schweitzerische Locomotiv und Maschienen Fabrik, Winterthur.		North Eastern Ry. of Switzerland.	Compound express locomotive with two driving axles, two other axles; tender with three axles.	16 / 26¼	26	72	20.8	191	23.46	1,372.7	33.0	55.0	31.6

		Exhibitor.	Manufacturer.	Railway.	Description of Locomotive.	Size of Cylinder. Diam.	Size of Cylinder. Stroke.	Diameter of Driving Wheels.	Total Wheel Base.	Steam Pressure.	Grate Area.	Heating Surface.	Weight on Drivers.	Weight of Engine in Service.	Weight of Tender in Service.
						in.	in.	in.	sq. ft.	lbs.	sq. ft.	sq. ft.	tons.	tons.	tons.
France.	a	Schneider & Co., Creuzot.		?	Express locomotive with two driving axles, five other axles; tender with five axles.	20	27½	98½	40.4	220	50.38	3,203.3	35.3	88.7	64.0
	1	Southern Ry. of France.	Schneider & Co., Creuzot.	Southern Ry. of France.	Compound freight locomotive with three driving axles; one other axle.	17½ 26½	25½	63½	21.8	220	23.13	1,895.9	45.7	58.5	
	2	Southern Ry. of France	Schneider & Co., Creuzot.	Southern Ry. of France.	Compound express locomotive with four cylinders, two driving axles, two other axles; tender with three axles.	13½ 21½	25½	84	24.8	206	26.47	1,950.8	36.3	59.4	39.2
	3	Southern Ry. of France.	Société Alsacienne, Belfort.	Southern Ry. of France.	Compound passenger locomotive with four cylinders, three driving axles, two other axles; tender with two axles.	13½ 21½	25½	69	25.1	206	26.47	1,950.8	46.0	63.3	26.8
	4	Fives-Lille Co., France.		Eastern Ry., China.	Compound freight locomotive with four driving axles, one other axle; tender with four axles.	20½ 23½	25½	49	22.3	176	26.68	1,737.7	61.7	71.8	55.2
	5	State Rys. of France.	Société Franco-Belge, Raismes.	State Railways of France.	Tank locomotive with two driving axles; two other axles.	11½	15½	52	15.2	176	10.76	406.7	22.0	36.3	
	6	State Rys. of France.	Schneider & Co., Creuzot.	State Railways of France.	Express locomotive with two driving axles, two other axles; tender with two axles.	17½	25½	79½	23.9	206	21.52	1,711.2	33.0	56.1	32.6
	7	State Ry. of France.	Baldwin Locomotive Works, Philadelphia.	State Ry. of France.	Compound express locomotive with four cylinders (Vauclain), two driving axles, two other axles; tender with four axles	13 22	26	84½	23.6	220	25.58	1,862.6	34.0	58.9	39.2
	8	Société Nouvelle des Etabs. Décauville aîné, Paris.		Narrow Gauge Ry., Vendée.	Tank locomotive with three driving axles: for narrow gauge, 39½ in.	9	14½	33	5.94	220	6.09	301.3	19.1	19.1	
	9	Northern Ry. of France.	Société Alsacienne, Belfort.	Northern Ry. of France.	Compound express locomotive with four cylinders, two driving axles, three other axles; tender with three axles.	18½ 22	25½	80	27.1	220	29.47	2,243.5	36.4	60.3	50.1
	10	Western Ry. of France.	Schneider & Co., Creuzot.	Western Ry. of France.	Tank locomotive, three driving axles, two others.	18½	23½	59½	25.9	176	19.37	1,417.1	48.4	64.8	
	11	Western Ry. of France.	Locom. Wks. of Batignolles.	Western Ry. of France.	Express locomotive with two driving axles, two other axles.	18½	26	79	24.5	162	19.15	1,318.1	31.5	50.8	
	12	Western Ry. of France.	Locom. Wks. of Sotteville.	Western Ry. of France.	Comp'nd express locomotive with four cylinders, two driving axles, two other axles	13½ 20½	25½	79	24.4	206	25.82	1,438.6	34.8	55.0	
	13	Société de Construction de Batignolles.		Paris-Lyon Railway.	Comp'nd express locomotive with four cylinders, two driving axles, two other axles	18½ 21½	24½	73½	23.9	220	26.15	2,080.0	33.9	61.1	
	14	L. Corpet and L. Louvet, Paris.		?	Tank locomotive with three driving axles; for narrow gauge, 39½ in.	12	17½	30	6.73	184	7.87	407.1	24.6	24.6	
	15	Paris-Orléan Ry.	Soc. Française de Constr. méc. (Cail), Paris.	Paris-Orléan Ry.	Compound express locomotive with four cylinders, two driving axles, two other axles; tender with three axles.	13½ 21½	25½	84	24.75	220	26.47	2,075.6	36.9	60.5	42.3
	16	Eastern Ry., France.	Locomotive Works at Epernay.	Eastern Ry., France.	Compound express locomotive with four cylinders, two driving axles, two other axles; tender with three axles.	13½ 21½	26	80½	23.9	220	27.11	2,239.7	37.5	63.8	46.7

Russia.	17	Maschienen Fabrik, Kolomna.	Narrow Gauge Ry., Russia.	Freight locomotive with four driving axles; for narrow gauge, 30 in.	14	11½	29½	8.9	176	12.37	538.0	25.1	23.1	
	18	Maschienen Fabrik, Kolomna.	South Eastern Ry., Russia.	Compound express locomotive with three driving axles, two other axles; no tender.	19½ / 28½	25½	72	26.5	169	23.13	1,491.3	43.7	67.2	
	19	Moskan-Kasan Railway, Brjänsk.	Moskan-Kasan Ry.	Compound freight locomotive (system Mallet), six driving axles; tender with four axles; for naphtha.	18½ / 28	25½	48	27.1	176	25.36	1,937.3	89.9	89.9	53.3
	20	State Rys. of Russia.	Pontiloff, St. Petersburg.	Russian State Rys.	Compound freight locomotive with four driving axles; tender with three axles.	19½ / 28½	25½	47	12.8	169	10.91	1,490.2	56.3	56.3	38.5
	21	State Rys. of Russia.	Pontiloff, St. Petersburg.	Russian State Rys.	Tandem compound express locomotive, four cylinders, two driving axles, two other axles; tender with three axles.	14½ / 21½	24	78½	24.8	191	28.19	1,449.3	33.1	62.2	38.5
United States.	22	Baldwin Locomotive Works, Philadelphia.	Great Northern Railway, Great Britain.	Freight locomotive with three driving axles, one other axle; tender with four axles.	18	24	61½	22.8	180	16.67	1,380.0	42.8	50.3	47.0
	23	Baldwin Locomotive Works, Philadelphia.	State Ry. of France.	Express locomotive with two driving axles, three other axles; tender with four axles.	17½	26	84½	26.8	220	35.0	2,095.8	35.9	69.4	39.2
Great Britain.	24	London & North Western Ry.; Crewe.	London & N. W. Ry.	Compound express locomotive with four cylinders, two driving axles, two other axles; tender with three axles.	15 / 20½	24	85	23.3	206	20.44	1,232.0	40.3	61.4	29.8
	25	Midland Railway, Derby.	Midland Ry.	Express locomotive with one driving axle, three other axles; tender with four axles.	19½	26	93½	23.1	185	24.43	1,104.0	20.7	56.1	54.9
	26	Neilson, Reid & Co., Glasgow.	Central Ry. of Holland.	Express locomotive with two driving axles, two other axles; tender with three axles.	18	26	84½	52.6	150	23.03	1,440.8	31.3	51.0	40.5
	27	Great Eastern Railway, Stratford.	Great Eastern Ry.	Express locomotive with two driving axles, two other axles; tender with three axles.	19	26	84	23.6	186	21.3	1,449.4	37.0	55.9	39.2
	28	North Eastern Railway, Gateshead.	North Eastern Ry.	Express locomotive with three driving axles, two other axles; tender with three axles.	20	26	73½	26.2	206	22.9	1,614.0	53.4	70.0	42.7
Switzerland.	29	Schweitzerische Locomotiv und Maschienen Fabrik, Winterthur.	Jura Simplon Ry.	Compound passenger locomotive with three cylinders, three driving axles, one other axle; tender with three axles.	(1) 19½ / (2) 21½	23½	60	20.8	206	24.75	1,509.6	49.6	61.0	30.9
	30	Schweitzerische Locomotiv und Maschienen Fabrik, Winterthur.	Central Ry. of Switzerland.	Compound express locomotive with four cylinders, with two driving axles, two other axles; tender with three axles.	13½ / 20	23½	68	23.1	206	23.67	1,404.2	33.0	53.1	33.0
	31	Schweitzerische Locomotiv und Maschienen Fabrik, Winterthur.	Street Ry., Lyon.	Street railway locomotive with three driving axles; for narrow gauge, 39½ in.	9½	13½	32	5.94	206	5.6	280.8	18.7	18.7	
	32	Schweitzerische Locomotiv und Maschienen Fabrik, Winterthur.	Abyssinian Railways.	Locomotive with three driving axles, one other axle; tender with four axles; for narrow gauge, 39½ in.	14½	21½	48	16.8	176	10.76	757.5	24.8	39.7	39.7
	33	Schweitzerische Locomotiv und Maschienen Fabrik, Winterthur.	North Eastern Ry. of Switzerland.	Compound express locomotive with two driving axles, two other axles; tender with three axles.	16 / 26½	26	72	20.8	191	23.46	1,372.7	33.0	55.0	31.6

		Exhibitor.	Manufacturer.	Railway.	Description of Locomotive.	Size of Cylinder.		Diameter of Driving Wheels.	Total Wheel Base.	Steam Pressure.	Grate Area.	Heating Surface.	Weight on Drivers.	Weight of Engine in Service.	Weight of Tender in Service.
						Diam.	Stroke.								
						in.	in.	in.	sq. ft	lbs.	sq. ft.	sq. ft.	tons.	tons.	tons.
Belgium.	34	Société des Forges, Haines St. Pierre.	State Railways of Belgium.	Express locomotive with three driving axles.	18	26	60	15.1	163	27.12	1,133.6	52.8	52.8	41.8
	34†	Société de St. Léonard, Liége.	State Railways of Belgium.	Freight locomotive with three driving axles for fast service.	18	26	60	15.1	162	27.12	1,133.6	52.8	52.8	
	35	Société des Ateliers, de Construction de la Meuse, Liége.	State Railways of Belgium.	Tank locomotive, with two driving axles; three other axles.	17	24	71	27.8	163	19.37	1,030.8	35.8	67.7	
	36	Société des Ateliers de Construction de la Meuse, Liége.	For use in factory.	Tank locomotive with two driving axles.	12½	18½	35½	7.6	175	10.76	479.9	28.4	28.4	
	37	Zimmermann-Haurez & Cie., Monceau sur Sambre.	State Railways of Belgium.	Tank locomotive with two driving axles; one other axle.	13½	18½	57	14.1	118	16.14	568.1	24.5	35.2	
	38	Société Franco-Belge, La Croyère.	Barry Railway, England.	Tank locomotive with three driving axles; one other axle.	18	26	51	20.8	154.4	30.44	1,089.4	53.8	62.2	
Austria.	39	Shops of the State Rys. of Austria-Hungary, Vienna.	Austrian State Railways.	Compound tank locomotive with three driving axles; two other axles.	20½ 20½	24½ 24½	51	25.4	191	25.07	1,407.9	48.2	77.3	
	40	Shops of the State Rys. of Austria-Hungary, Vienna.	Austrian State Railways.	Compound express locomotive with three driving axles; two other axles; No. 6.	20½ 21½	28½ 28½	72	27.9	206	33.36	2,080.7	47.9	76.7	
	41	Krauss & Co., Linz Danube.	For Ministry of Public Works.	Tank locomotive for narrow gauge, 30 in.; three driving axles; one other axle.	11½ 11½	15½	32	13.2	170	10.76	500.3	27.0	27.0	
	42	Vienna Locomotive Works, Floridsdorf.	State Rys., Austria.	Compound express locomotive, two driving axles, two other axles; tender with three axles.	19½ 20½	28½ 28½	64	24.1	191	33.28	1,546.3	31.6	61.3	41.8
	43	Locomotive Works of G. Sigl, Wiener, Neustadt.	State Railways, Austria.	Compound freight locomotive with four driving axles; one other axle.	21½ 21½	34½ 34½	51	22.5	191	35.26	2,442.5	62.7	73.4	
	44	Locomotive Works of G. Sigl, Wiener, Neustadt.	Emperor Ferdinand Ry.	Express locomotive with two driving axles, three other axles; tender with three axles	18½	28½	79	27.6	191	31.30	1,032.3	30.8	66.5	40.8
Hungary.	45	Locomotive Wks. of the Hungarian State Rys., Budapest.	State Rys. of Hungary.	Tank locomotive with four driving axles; for narrow gauge, 30 in.	13½	19½	30	13.8	170	9.7	526.0	70.5	98.5	
	46	Locomotive Wks. of the Hungarian State Rys., Budapest.	State Rys. of Hungary.	Compound freight locomotive (system Mallet) with four driving axles; tender with three axles.	15½ 22½	24	49	19.8	191	37.98	1,604.3	62.6	62.6	37.6
	47	Locomotive Wks. of the Hungarian State Rys., Budapest.	State Rys. of Hungary.	Compound express locomotive with two driving axles, three other axles; tender with three axles.	19½ 20½	28½ 28½	68	26.6	191	30.34	1,615.9	64.0	71.8	44.2

48	Hannoversche Masch. A. Gesellschaft, Hanover.	State Ry. of Prussia.	Compound express locomotive with four cylinders, two driving axles, two other axles; tender with three axles.	13 30½	23½	82½	24.9	276	24.43	1,277.2	34.4	68.0	36.3
49	Henschel & Son, Cassel.	State Railway of Prussia.	Passenger tank locomotive with two driving axles and two other axles.	17 27½	27½	63	22.4	176	16.80	1,047.4	34.5	58.4	
50	Henschel & Son, Cassel.	State Railway of Prussia.	Tank freight locomotive with five driving axles.	17 20½	21½	47	22.64	176	25.39	1,479.7	78.7	78.7	
51	Maschinen Fabrik, Esslingen.	State Rys. of Wurtemberg.	Rack locomotive with four cylinders, three driving axles, one other axle. A, Adhesion; R, Rack.	4.16½ 2.16½	21 21½	48 42½	18.5	206	15.06	1,209.2	46.2	59.6	36.1
52	A. Borsig, Tegel, Berlin.	State Rys. of Prussia.	Express locomotive with superheater, two driving axles, two other axles; tender with three axles.	19½	23½	78	24.4	176 Superheater	24.43	1,167.5 1,301.3	35.6	62.2	
53	Kraus & Co., Munich.	?	Compound express locomotive with auxiliary cylinders, two driving axles, four other axles.	17½ 27½ 10½	20 15½	73½ 39½	29.5	206	31.31	2,054.9	31.0 45.8	74.8	
54	Kraus & Co., Munich.	State Railways of Bavaria. For factory use.	Passenger tank locomotive with two driving axles; one other axle.	17½	22	64½	29.1	176	21.09	1,151.6	32.0	75.7	
55	Kraus & Co., Munich.		Tank locomotive; narrow gauge, 24 in.; two driving axles, one other axle.	7½	11½	24½	7.92	176	4.30	183.2	8.8	11.7	
56	J. A. Maffei, Munich.	State Rys. of Bavaria.	Mallet compound freight locomotive, two cylinders and two driving axles, one other axle; tender with four axles.	15½ 25	24½	53½	27.1	220	28.51	1,604.9	63.8	73.7	40.2
57	Vulcan Works, Stettin.	State Rys. of Prussia.	Compound freight locomotive with four driving axles; tender with three axles.	20½ 29½	24½	45	14.9	176	24.21	1,506.4	57.2	57.2	36.3
58	Schwartzkopff, Berlin.	State Rys. of Prussia.	Compound passenger locomotive with two driving axles, two other axles; tender with three axles.	18½ 36½	23½	60	24.4	176	24.73	1,269.7	33.0	56.1	36.2
59	Sächs Maschienen Fabrik, Chemnitz.	State Rys. of Saxony.	Compound express locomotive with four cylinders, two driving axles, three other axles; tender with four axles.	13½ 21½	26	79	30.2	220	26.04	1,773.4	35.2	74.5	47.2
60	Sächs Maschienen Fabrik, Chemnitz.	State Rys. of Norway.	Compound passenger locomotive with three driving axles, two other axles; tender with four axles.	17½ 26½	25½	57	22.7	191	20.94	1,202.1	39.8	56.2	31.9
61	Sächs Maschienen Fabrik, Chemnitz.	Rys., Java, East India.	Compound tank locomotive with three driving axles, one other axle; for crude oil and for narrow gauge, 42 in.	11 16½	15½	44½	11.9	185	9.68	422.8	18.7	27.8	
62	G. Ansaldo & Cie., Sampierdarena.	Mediterranean Ry., Italy.	Compound express locomotive with three driving axles, two other axles; tender with three axles.	21½ 31½	26½	72	23.1	191	27.98	1,412.3	49.5	72.4	36.0
	Mediterranean Ry. Shops, Florence.	Mediterranean Ry., Italy.	Compound tank locomotive with four cylinders, three driving axles, two other axles; with water tender.	15 22½	25½	76½	27.6	220	32.38	1,793.7	47.9	73.2	39.9
	Ernesto Breda, Milan.	Mediterranean Ry., Italy.	Express locomotive with two driving axles, two other axles; tender with three axles.	16½	23½	76½	18.8	206	25.5	1,719.5	32.1	52.9	32.5

Germany.

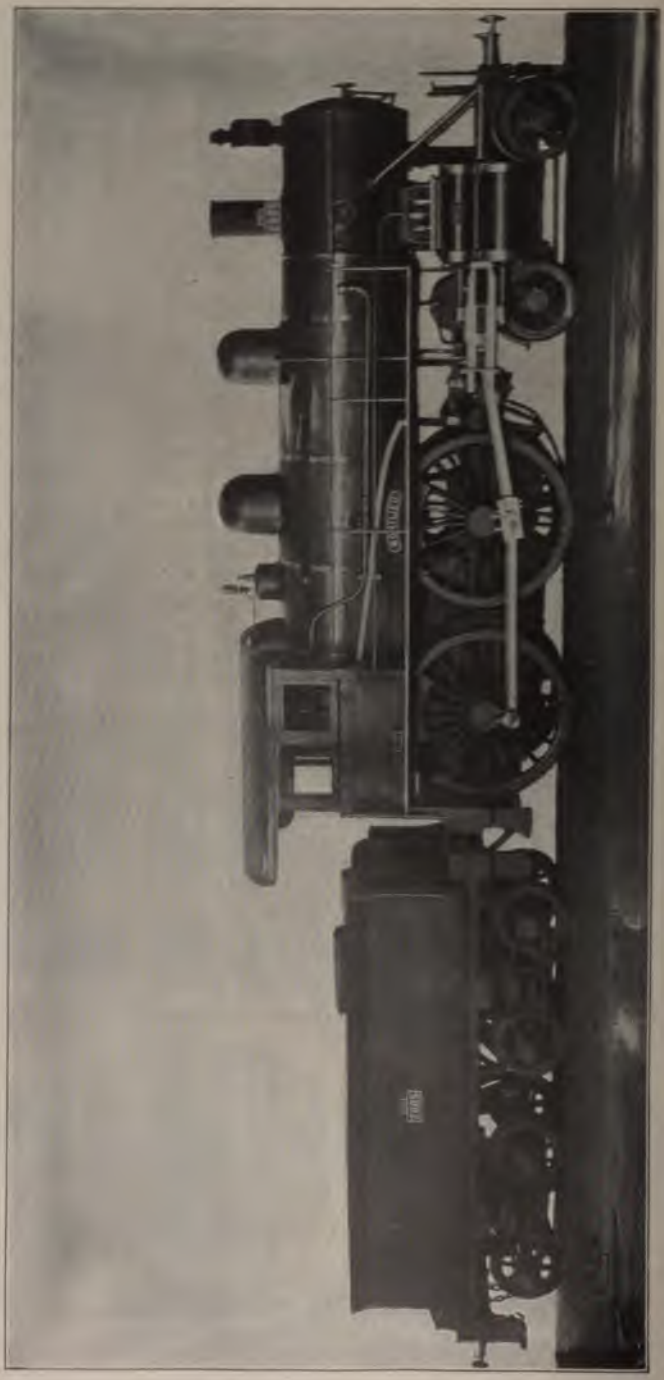


Fig. 349.

FIG. 350.

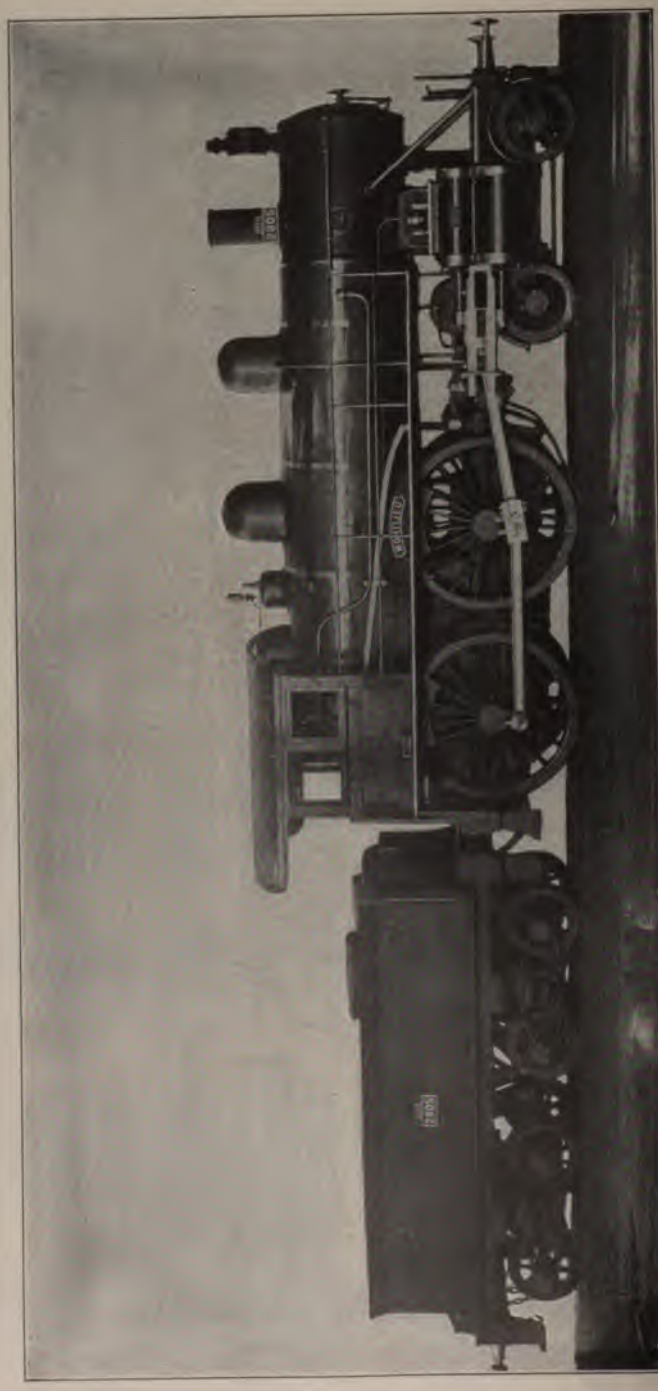


Fig. 349.

FIG. 350.

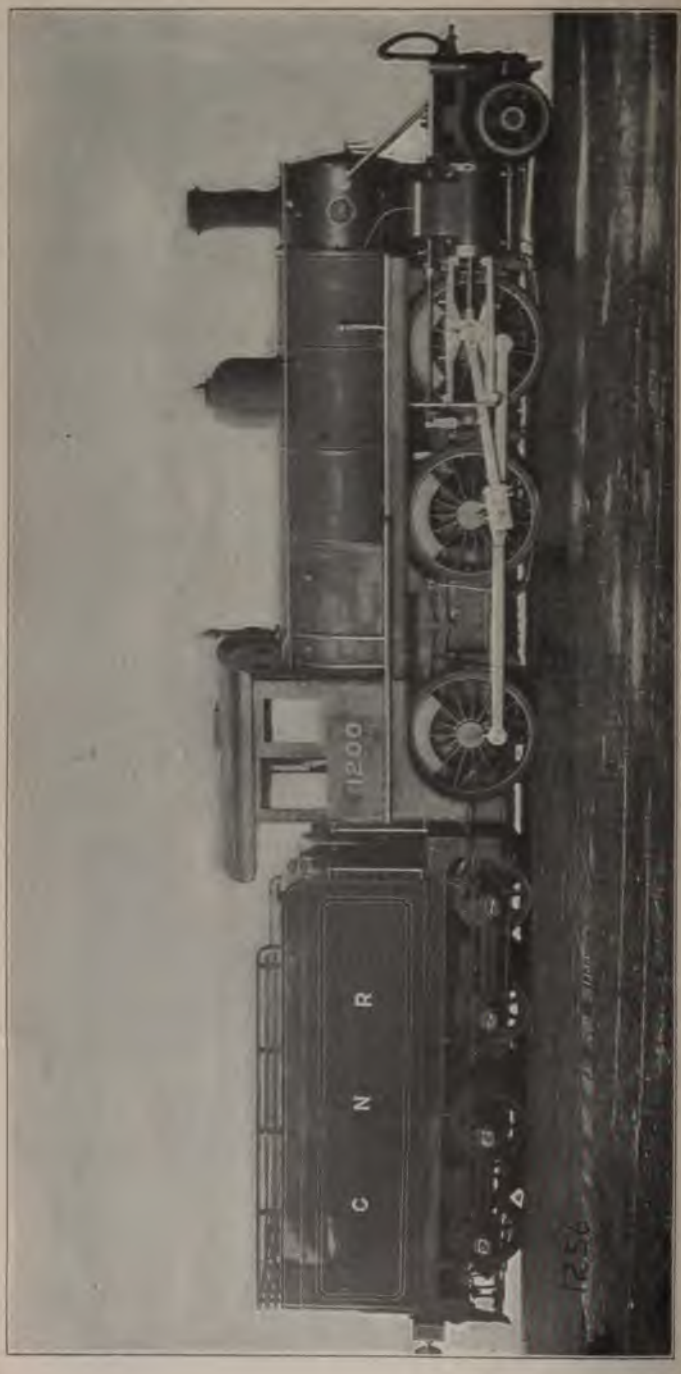
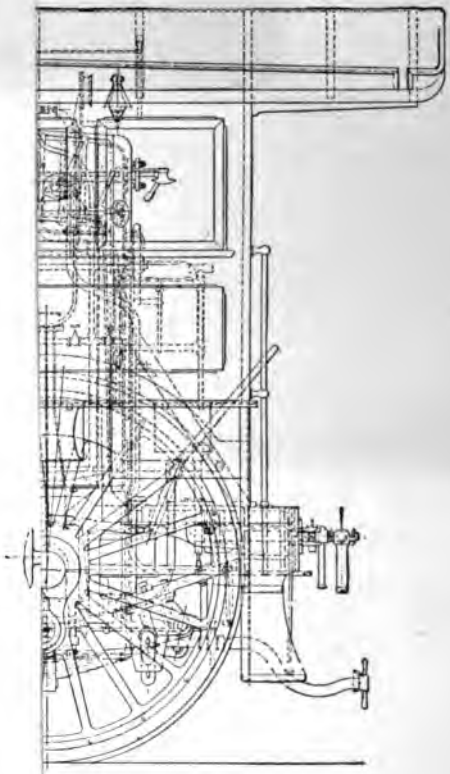


Fig. 351.

STORM BULL.



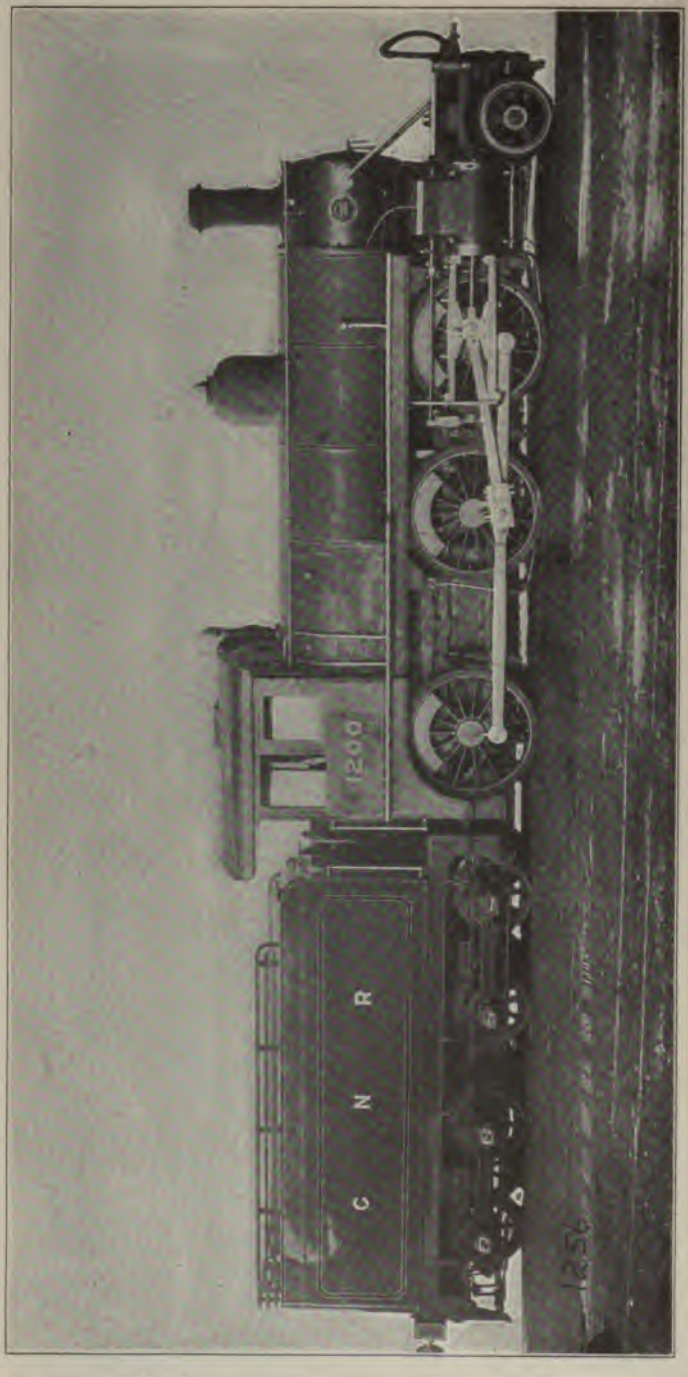


FIG. 351.

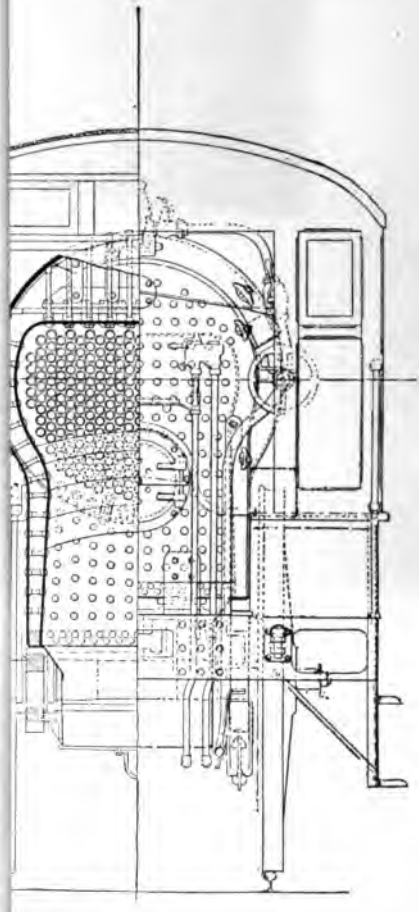


FIG. 355.

DISCUSSION.

Mr. S. E. Freeman.—I would like to ask Mr. Bull to what the economy of the de Glehn engine is mostly due. Is it due to the valve gear employed, or to some other specially designed part; for instance, the cylinders, valves, etc.?

Prof. Storm Bull.—They claim that they get a better distribution by the Walschaert valve motion, but I do not suppose that the economy is increased very much by it. I think that the increase in economy which they get is due to the compounding, the same as here. The compound used there is not only economical, but it is also very convenient.

Mr. Freeman.—I might put that question in another form: Does the compound engine of this design, with its Walschaert valve gear, show greater economy than a compound engine of like design with the usual type of link gear?

Professor Bull.—I do not know.

Prof. W. F. M. Goss.—I am glad to note the emphasis that Professor Bull has given to the de Glehn compound locomotive, better known in this country perhaps as that of the Northern Railway of France. I believe that type of engine should commend itself to the railroad men of this country. American locomotive designers have adopted simplicity as a fundamental plank in their platform, and any design which multiplies parts in locomotives has been slow to gain a footing. No doubt we have been right. The question is what degree of complication is admissible in order that a proper solution of a given problem may be had. This type of engine, as Professor Bull has explained, has four complete engines, in the same sense that our simple American locomotives have two complete engines. There are two outside cylinders and two inside cylinders. The two inside cylinders connect with a crank axle in the front, and the two outside cylinders connect with pins in the wheels of the second or rear axle. There is a great subdivision of power, and there are many advantages which result from this fact—advantages which, if they could gain them, American engineers would appreciate. For example, the reciprocating parts of the French engine are perfectly balanced, the cranks of the two systems of engines being placed opposite each other. This is a result which, while much desired, can never be attained under the common practice of this country. Again, the arrangement permits a dis-

tribution of power throughout a greater length of frame, and this is something the advantage of which American designers will appreciate. With the enormously large cylinders and the high steam pressures now common in American locomotive practice, the strains introduced are enormous, and frames must be extremely heavy or the engine will prove structurally weak. The desirability of subdividing power is further shown in the difficulty which is now being encountered in keeping the crank pins and axles cool on the modern large engines. Crank pins of to-day are often as large as axles were a few years ago, but still they give trouble by heating. By the adoption of the French design there would be four cranks, four connecting rods, and four crossheads instead of two. The size of all the parts would be diminished, and, as a consequence, their design could be better suited to the work to be performed. The objection to the larger number of parts is in the assumed greater chance of derangement and increased cost of repairs. This assumption is, however, one that is not well made. The chance of derangement where a few parts are involved which are necessarily poorly designed and overworked is greater than when double the number of parts better suited to the service to be rendered are involved. I venture to say that if two 17-inch by 24-inch engines were put at the head of a train and treated as one engine, neither failures nor cost of repairs to machinery would be greater than when the same work is done by a modern 20-inch by 26-inch engine. This statement concerns failure and repairs to machinery alone. If it is true, the objection to increased number of parts in the French engine cannot be seriously urged.

Again, there is the question of room along the right of way. There are simple engines now running whose cylinders clear obstructions along the right of way by less than an inch. Two-cylinder compounds could not be substituted for these. The adoption of the compound system, therefore, which is desirable and which is bound to come, will necessitate the use of some type of four-cylinder compound; and if we are to accept a four-cylinder engine, I submit that the compound of the Northern Railway of France is worthy of our attention. In saying this I do not forget or undervalue other excellent types of four-cylinder compounds.

Mr. Reed.—I have been very much interested in the reading

of this paper, because it calls attention to some peculiar types of engines which are striking from many standpoints.

Fig. 347 shows an engine which was especially noticeable on account of the many complications which were embodied in its design. There is one point to which the limits of the paper did not permit of reference, and yet one which may be of general interest. A connecting rod from the rear wheel ran mysteriously into a box just under the cab, and there it was connected with a weight sliding in proper guides. This additional and heavy weight moved backward and forward with each revolution of the drivers, for the sole purpose of counterbalancing the reciprocating parts of the engine; showing to what extent complicated mechanism is sometimes introduced, when in practice a more simple and nearly as effective device will accomplish the result.

*Professor Bull.**—In reference to the last observation I might say that there are necessarily a great many important things which I might have stated in the paper, but which I did not include, either because I overlooked them or because I did not want to make the paper too long.

In closing the discussion I may, perhaps, be permitted to say that the object of this paper was to place on record—in the *Transactions* of the Society—the state of the art of locomotive construction at the end of the nineteenth century, and as revealed at the Paris Exhibition. As a consequence it was deemed necessary to introduce a large number of illustrations, and as the details were shown so plainly on most of these, but brief explanations were included in order to prevent the paper from becoming too voluminous. Because of this fact the reading matter may seem rather meagre, but this apparent shortcoming is explained by what is stated above.

* Author's closure, under the Rules.

No. 904.*

BLUE-PRINTING BY ELECTRIC LIGHT.†

BY H. G. REIST, SCHENECTADY, N. Y.

(Member of the Society.)

In large manufacturing establishments the short and frequently dark and cloudy days of winter are the occasion of great inconvenience and delay in the production of blue-prints. A printing plant suitable for making the required number of prints in summer will be entirely inadequate for the same production in winter. Unfortunately, this is a department which ordinarily cannot be worked overtime in order to make up for the loss. Suffering much on this account because of the large number of blue-prints required, the General Electric Company some time ago tried several methods of printing by electric light. In one plan a small room was arranged with 9 arc lamps placed about 18 inches apart, suspended from the ceiling, and by a suitable arrangement of reflectors a large portion of the light was thrown downward on printing-frames arranged on trucks, being the same frames which are used ordinarily for printing by sunlight. The reflectors are hinged so that the light may be thrown to the position wanted. With a rapid printing paper the time required for printing with this arrangement is from six to eight minutes.

Another arrangement for printing, and one which is being used extensively with somewhat more satisfactory results, is shown in the accompanying illustrations. It will be seen that there are 2 lamps, each being a standard 5-ampere, 110 volts enclosed arc lamp, enclosed by a metal hood a little larger in

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* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† For further discussions on this topic consult *Transactions* as follows:

No. 308, vol. ix., p. 696: "Large and Enlarged Photographs and Blue Prints." R. H. Thurston. Also vol. viii., p. 722, No. 259–48.

No. 847, vol. xxi., p. 586: "A Curved-glass Blue-printing Machine." P. M. Chamberlain.

size than the printing-frame. The hood is strongly constructed of sheet iron with parabolic sides which are finished on the inside with white enamel, having good reflecting power. The hood is supported on the lamps, and in order to prevent the parts from overheating, an effective ventilating device is provided at the top. There are also handles on the side so that it may conveniently be moved along the track. The lamps in turn are supported on a small trolley arrangement, made from the parts used for sliding folding doors, and on each side there is a conducting wire from which a small trolley wheel carries the current to the lamps. The tracks on which the lighting device is supported are of sufficient length so that 5 printing-frames can be set under each of them, and the lamps readily moved to cover any one of them. The printing-frames which we are now using are the standard frames used for sun-printing, although they can be somewhat simplified if they are made specially for printing by electric light. The lamps are enclosed in white opal globes. This diffuses the light, and the white interior of the reflector projects it downwards so that the area over the print to be made is very uniformly lighted, there being no perceptible difference in the tone of the print in the middle from what it is in the corners. When the first print has been exposed a sufficient length of time, the light and the hood are moved along the track to the next frame, while work is begun on the first one to replace the printing paper or tracing as the case may be.

The time required for printing naturally varies widely with different tracings and different makes of paper. In general, it may be stated that the time required is 3 or 4 times as long as with bright sunlight. With one grade of paper which we are using, the time by sunlight in the middle of the day during February is about 35 seconds, and by electric light 1½ minutes. It will readily be seen that there are great advantages in having a printing establishment which is independent of the season or of the condition of the weather. With an electric equipment blue prints may be put into the factory almost immediately after the completion of the tracing, regardless of the time of day.

In summer it is possible to print all the time duri
hours, and the per cent. of time lost on account of
rainy weather is small. In winter it is not p

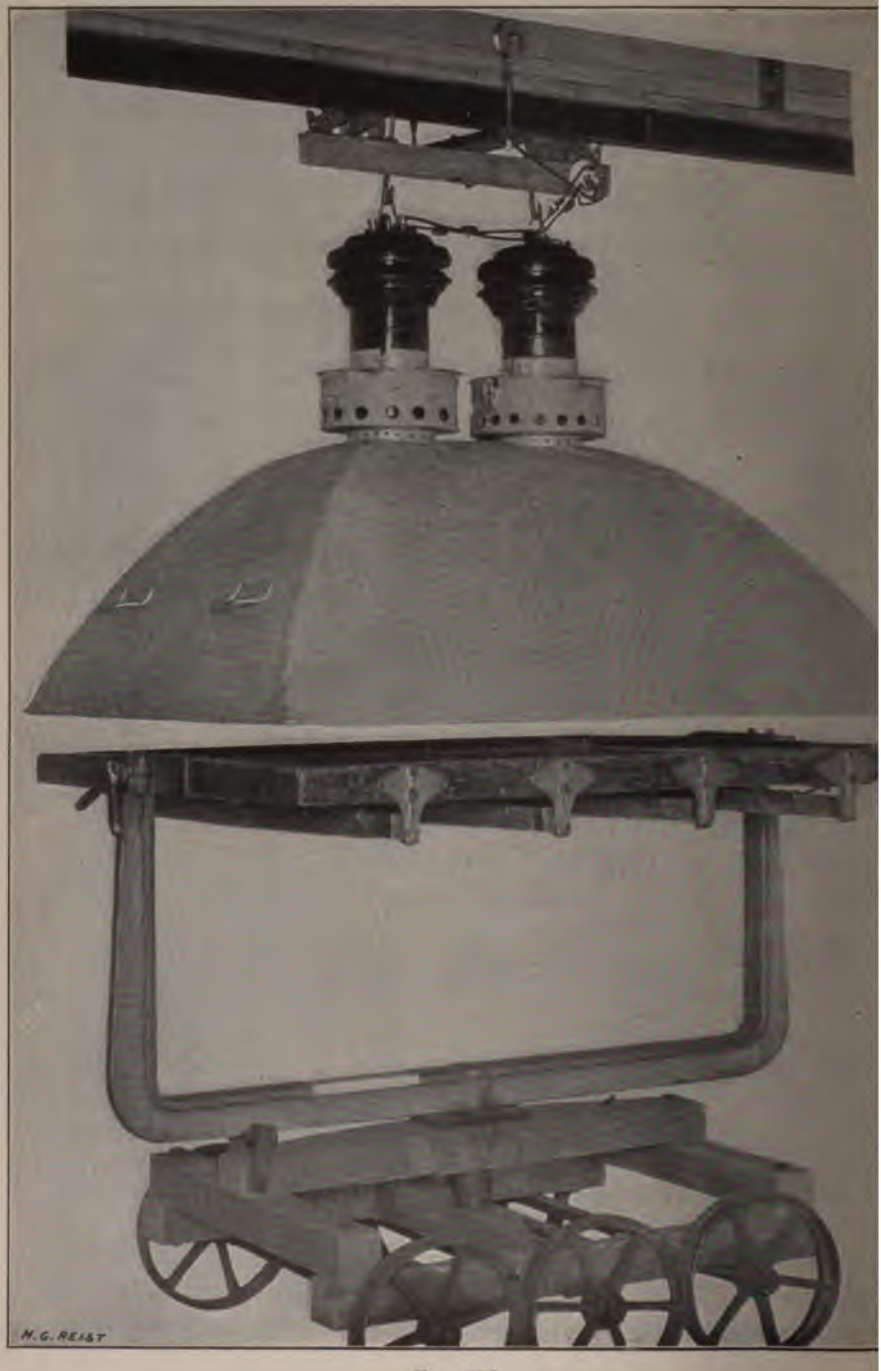

FIG. 356.

Fig. 357.

after about 4 o'clock in the afternoon, and the amount of bad weather is a large part of the total time. In the belt in which I live it is cloudy as much as 60 per cent. of the time during the months of December and January. In cloudy weather the time

Fig. 358.

required for printing is about 8 to 10 times as great as on a clear day, and on a rainy day it is not possible to print at all out of doors, except by a specially devised water-proof printing-frame; at such times the time required for changing prints is greatly increased, as the frame has to be wiped to keep from injuring the tracing.

From curves of the actinic value of sunlight for different times of the day and for different seasons, I have calculated that with a paper so rapid that it will print in 8 seconds in the sun at noon during the month of July, the mean time required for making a print in January for the hours from 8 to 12 and from 1 to 4 is 2.33 minutes. Similarly, in July the mean time for the hours above, except that the time is extended to 5.30 in the afternoon, is 0.59 minutes, or the mean time for clear days during the year is 1.40 minutes.

Taking all the above into account, I find that the average number of prints made by one operator in winter per day is 26.4. In summer the number of cloudy days are about 25 per cent., and the average number of prints that may be made by one operator are 57.3, or more than twice as many as can be made in winter.

The cost of making prints by electric light is much smaller than one would expect, and the following figures indicate that it is cheaper to use artificial light than sunlight for this purpose.

In printing by electric light it is assumed that the cost of electricity is 12 cents per kilowatt hour, which I believe is a fair commercial rate. The lamps are turned off when not in use. They are in use only 85 minutes for each operator, as shown in the table below. Each lamp requires 550 watts and the cost for the two lamps is 18.7 cents per day. Labor is assumed at the rate of $1 per day.

	Sunlight.	Elec. Light.
No. of prints per day, mean per year.....	41.9	56.5
Cost of printing, per print	2.39 cts.	2.09 cts.

The time required for changing a print in sunlight is a little longer then when the artificial light is used, because the whole frame has generally to be moved, and the frame has to be adjusted to the proper angle to get the most effective sunlight. The time allowed for changing prints is 7 minutes when printing by electric light; 8 minutes when printing by sun, while when printing during a rainy day as much as 20 minutes may be required.

It will often be found an advantage to use e
ing as a supplement to the ordinary method,
method is not entirely superseded. Among oth
may be mentioned the smaller space required for

for a given output than for sun printing; also, there will be less paper wasted, as the time for printing is much more uniform.

This method of making prints will especially appeal to manufacturers who are located where there is a tendency to have fogs or where tall buildings may interfere with the normal sunlight.

DISCUSSION.

Mr. John Balch Blood.—In connection with this subject, it is interesting to note that the use of electric light for blue-printing is appreciated in England as well as in this country. In the *London Engineering* for May 3, 1901, on page 58, an advertisement appears for an arc lamp, duplex, radial photo copying frame, the price of which is £27 10*s.*, or about $133. The appar-

FIG. 359.

atus is shown in Fig. 359. The lamp and lowering gear are not included in the price.

The advantages given out in the advertisement are as follows:

(*a*) Copying indoors at any time where electric current is available.

(*b*) The lamp being wired and fixed in desired position, the

pedestal and frame are placed to receive it, and rest there permanently—no shifting, no carrying.

(*c*) Immunity from accident ensured by the frame remaining on the pedestal.

(*d*) The horizontal position (when placing in or taking out tracing and copies) is the most convenient for operators.

(*e*) Two full-size tracings can be copied at one operation.

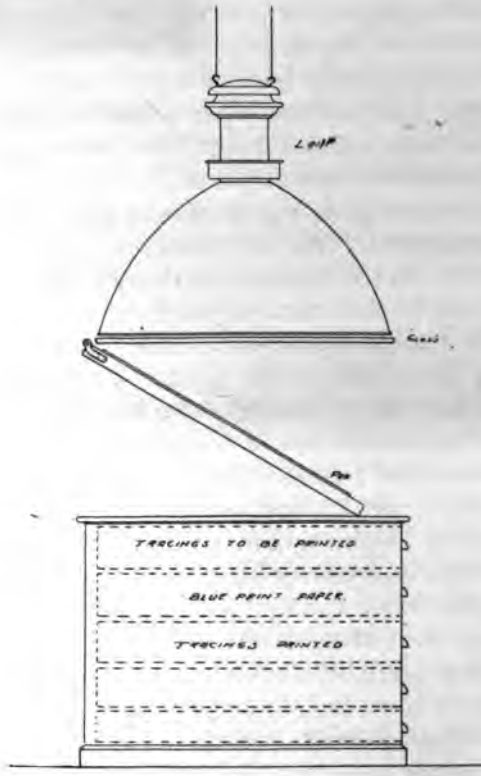

FIG. 360.

The printing-frames as shown in the illustration with Mr. Reist's paper would seem to be expensive and unnecessary for electric lighting work and also inconvenient for use. The simplest and best form of frame which I have seen is the heavy piece of plate glass, say $\frac{3}{8}$ to $\frac{5}{8}$ of an inch thick, depending upon the size, resting on a soft pad. This style of frame has many advantages, the first being simplicity; the second, that the work

can be inspected while being put in; and the third, that no gear is necessary for turning the frame upside down.

It seems useless to have trucks with wheels for wheeling round the printing-frames where electric lights are to be used. A printing frame for electric light is shown in Fig. 360, which would seem to be simpler and much more convenient than that shown in Mr. Reist's paper.

Mr. S. L. G. Knox.—It may be interesting to state that the inside of the frame should be painted with white enamel. You must not have it too bright. One of our men tried to make a frame bright inside, and the result was that one part of the tracing was reflected back on the other parts, and the print, when taken out, was most extraordinary; the drawing number appeared in half a dozen different places.

The paper does not bring out the whole economy which is derived from this process. We are arranging now to do all of our blue-printing by electric light, even though the sun is shining brightly, because we find that we can do it cheaper than we can by pushing the frames outside and tilting them to the sun and then dragging them back inside again. With this process, the frames do not have to be handled. In the old way the limit of our blue-print production was in the ability and strength of the boys to handle these frames. It took only thirty seconds to make a blue-print, but it took seven or eight minutes' time to get the frame out in place, back again, and ready for another exposure. With this electric-light blue-printing, you do not need to move the frame at all.

Another important thing is this. Nobody thinks of sending out a letter on a business matter without keeping a copy of it, but frequently we have had to prepare and send out rush drawings in answer to a telegram, perhaps late in the afternoon on a rainy day when we could not make prints, and the result was that we sent away sketches which we were afterwards obliged to ask the recipient to send back to us. With this process of electric-light printing, we can get an order at 29 minutes past 5, and can make a blue print and have it ready at 30 minutes past 5—as quick as we can copy a letter in our letter-press copy book.

Mr. Thomas W. Capen.—The machine described by Mr. Blood is in use by Fraser & Chalmers, and has been for some time, I believe, with entire success. I understand that they are now

being made by a firm in Pittsburg, and are furnished at a cost of from $400 to $500 installed.

Mr. C. W. Hunt.—We have been using this apparatus very successfully in our blue-printing office for about two years. It is very convenient to use, as there is no frame to handle, and no heavy glass to raise up when inserting the papers. The machine is a vertical cylinder about 2 feet in diameter and 4 feet high, with an arc light in the axis. This light is slowly lowered from the top to the bottom by clock work, giving every part of the prints an equal amount of exposure. The print is wrapped on the outside of the glass cylinder, and held in position by a sheet of canvas cloth. When once in operation, it was found so convenient that we abandoned sun printing.

Mr. S. T. Wellman.—In connection with our experience, I think the cost of the apparatus was somewhere between $200 and $300, but the saving for the whole system paid for it in less than three months, and one boy did all the work, whereas formerly we kept two or three boys at work, and then only made a small portion of our blue prints; we had to go outside and hire some of them made.

Mr. Harry Sawyer.—I would like to ask the gentlemen who have had experience with this class of apparatus, if they have had trouble on account of the excessive heating of the glass. I am led to ask this question by some statements made to me while visiting the works of a large engineering company in Philadelphia. They had provided a tin-lined box, perhaps 4 by 5 feet square and 20 feet long, open at both ends, and placed in a horizontal position. The printing frame was placed in a vertical position a short distance from one end of the box, and the arc lights were placed at the other end. This arrangement of reflectors concentrated the heat, as well as the light, on the glass, causing some trouble.

Are not the laws governing reflection of light and heat about the same? It has been a question in my mind whether or not an arrangement could be made which would concentrate the light on a glass without concentrating the heat in about the same proportion.

Mr. Hunt.—There is no difficulty whatever from the heat of the light. There is a switch for turning the current on and off, located near the operator's hand, so that to protect his own eyes from the light he immediately turns it off when the paper is

printed. The light is only running when they are exposing the print.

Mr. Reist.—The apparatus which I described in my paper is arranged in this way: There is a ventilator arranged in the top of the device which acts as a chimney and keeps drawing in cold air from the room; and besides, the light is always turned off immediately after the printing is completed.

Mr. Wellman.—We have had no trouble with heating at all. We have had the apparatus in use something like a year and a half, and there have been no breakages and no trouble with it whatever.

Mr. Knox.—It is not claimed that the apparatus described in the paper is better than the cylinder, but the outfit costs probably one-tenth as much as the cylinder apparatus, and prints just as quickly.

No. 905.*

THE PRACTICAL APPLICATION OF SUPERHEATED STEAM.†

BY GEO. A. HUTCHINSON, ANACONDA, MONT
(Junior Member of the Society.)

THE very general use of superheated steam throughout Europe, and particularly in France and Germany, has interested the writer for some time past, the more so because of the remarkable economy attained, and because of the general skepticism with which any allusion to its use is met in this country.

To emphasize the fact that its employment has passed far beyond the theoretical stage, the following table has been prepared showing the horse-power, on a basis of ten square feet of heating surface, of boilers in electrical plants in certain German cities, all of which boilers have been equipped with superheaters by a single builder.

	Boiler Horsepower.
Munich	1,610
" Central Station	750
Berlin General Electric Co.	560
" " "	540
" " "	2,600
" " "	2,600
Bruhl	775
Essen	1,610
Mannheim	1,610
Frankfort	480
Breslau	2,400

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† For further discussions on this topic consult *Transactions*, as follows:

No. 572, vol. xv., page 313: "Maximum Contemporary Economy of High-pressure, Multiple-expansion Steam Engine." R. H. Thurston.

No. 689, vol. xvii., page 488: "Superheated Steam." R. H. Thurston.

No. 720, vol. xviii., page 160: "Promise and Potency of High-pressure Steam." R. H. Thurston.

No. 853, vol. xxi., page 788: "Pumping Engine Test with Superheated Steam." E. H. Foster.

No. 906, vol. xxii., page 939: "Superheated Steam." E. H. Foster.

These figures seem very small when we think of the large electrical plants with which we are familiar in this country; but the total electrical station capacity available for all purposes in Germany, little more than a year ago, was only 224,000 kilowatts, as against 2,000,000 kilowatts for the United States.*

Let us begin our consideration of the subject by first defining a superheated vapor, and then applying the known law for superheated steam to a concrete case. "A dry and saturated vapor, not in contact with the liquid from which it is formed, may be heated to a temperature greater than that corresponding to the given pressure for the same vapor when saturated; such a vapor is said to be superheated."† The equation for superheated steam is $pv = 93.5T - 971\ p^0$, in which p is the absolute pressure in pounds per square foot, v is the volume in cubic feet, and T is the absolute temperature in degrees Fahr. Saturated steam at 150 pounds boiler pressure has a temperature of 365.7 degrees Fahr. If a pound be superheated to 600 degrees, the volume remaining constant, or about 2.756 cubic feet, according to the above equation, the pressure will become about 202 pounds. One pound of saturated steam at the same temperature would probably develop a pressure exceeding 1,500 pounds per square inch. If, however, as is the case through expansion, the pressure of the superheated steam remains practically constant, and the volume increases, instead of 2.756 cubic feet, 3.674 cubic feet is the space occupied by one pound. With a feed-water temperature of 100 degrees, 1,125.5 British thermal units must be added to one pound to evaporate it at 150 pounds pressure. A further addition of 112.6 British thermal units will superheat it to 600 degrees, and increase the volume from 2.756 cubic feet to 3.674 cubic feet. In other words, ten per cent. additional heat increases the volume of the steam 33⅓ per cent.

The relations may be exemplified by a consideration of the accompanying diagram, Fig. 361. Suppose that a given weight of saturated steam has the volume ag, and that an equal weight of superheated steam has the volume ah. If the saturated steam expands adiabatically in a non-conducting cylinder—that is, the intrinsic energy of the steam is turned into work without loss or gain of heat—the exponential curve gh, $pv^{1.135} = c$, will represent, approximately, the process, and the area $aghif$ the work done.

* Philip Dawson, *Engineering*, April 27, 1900.

† C. H. Peabody, "Thermodynamics of the Steam Engine."

The steam loses heat, and a portion condenses during the process, as may be seen by comparing the lines *gc* and *gh*, *gc* being the curve of saturated steam, which follows approximately the relation $pv^{1.0646} = c$. If the superheated steam expanded adiabatically the curve *bc* would be plotted from the relation $pv^{1.333} = c$. At *c* the point of saturation would be reached, and from then on condensation would ensue, and the curve *cd*, $pv^{1.135} = c$, would represent the process thereafter. The work performed would be

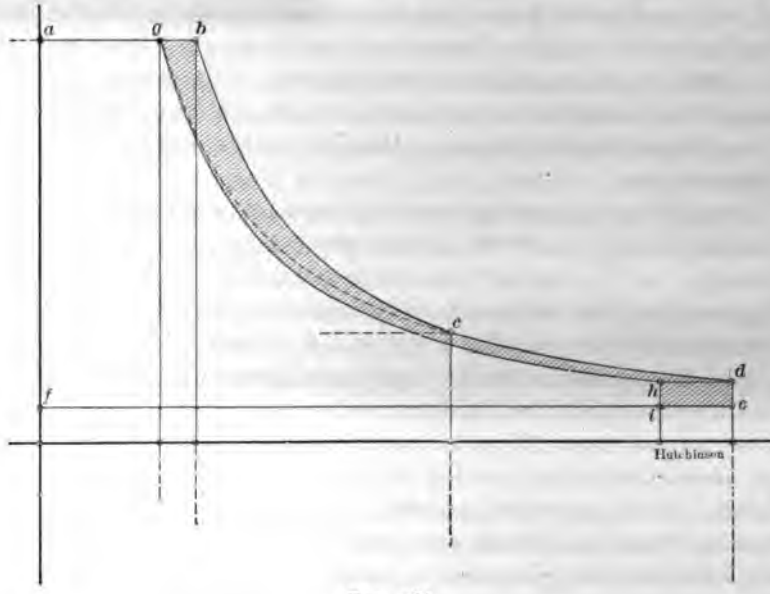

FIG. 361.

represented by the area *abdef*, and the gain due to superheating by the portion which is cross hatched.

As superheated steam is more nearly in the condition of a perfect gas, its specific heat is low, and the superheat is soon lost during expansion. To illustrate, the specific heat of saturated steam, which varies with the temperature and pressure, is given for the following absolute pressures:*

Pressure in pounds per square inch.	5	50	100	200	300
Temperature, ° F.	162.3	280.9	327.6	381.7	417.4
Specific heat	1.607	1.237	1.122	1.001	0.931

* "Thermodynamics," Peabody.

For superheated steam the specific heat at constant pressure is about .4805, and for air it is .2375.

There is always a loss by radiation in the steam pipes and passages, as well as a loss due to clearance, and to the heat absorption by the cylinder walls, which are exposed periodically to the temperature of the exhaust. The advantage of superheated steam may be attributed to three considerations: at high temperature it behaves like a gas, and a considerable amount of heat may be abstracted before any portion will liquefy; a moderate addition of heat produces a proportionately large increase in volume, and diminishes the weight of steam used per stroke for a given amount of work; it has a greatly reduced thermal conductivity as compared with saturated steam, and therefore the heat absorbed by the cylinder walls becomes a fraction only of what it would otherwise be.

To gain any advantage from the increase of volume the superheating should be carried to the highest degree practicable. Experience has shown that the steam should be heated 125 to 175 degrees above the saturation temperature, in order to prevent condensation before cut-off. Even in a non-conducting cylinder it would be impossible, with a high initial pressure, to preserve the steam in a superheated condition till the end of expansion. With lower pressures an initial temperature of 650 degrees is necessary in order, theoretically even, to permit of superheat in the exhaust. In the engine as actually constructed there are many disturbing elements. From one-quarter to one-half of the so-called dry steam entering the cylinder is condensed during admission, and the most of it goes out of the exhaust port without having performed any work. Under the best conditions an initial condensation of at least twenty per cent. is to be expected. There is frequently, during expansion, a partial reëvaporation of the steam condensed during admission, and tests on multiple-expansion engines, driven with saturated steam, and equipped with cylinder jackets and reheating receivers, have sometimes shown the steam to be slightly superheated at release in the low-pressure cylinder.

Though the advantage to be derived from superheated steam was appreciated fifty or sixty years ago, the mechanical difficulties encountered stood in the way of its widespread adoption until within the past five or ten years. The danger of burning out the metallic surfaces, exposed to the high temperatures, had to be met, and while it cannot be eliminated, the fact that there are

thousands of such installations, both large and small, in every-day use at the present time, is good evidence that it has been minimized.

The use of high fire-test mineral oils for cylinder lubrication, and of metallic or asbestos packing, disposes of the other most serious questions. More careful and more plentiful lubrication is required unquestionably than with saturated steam, for the presence of condensed steam on the cylinder walls is an undoubted aid to their proper lubrication. The temperatures are not as high as those of gas-engine cylinders, and, in fact, unless the steam is highly superheated, the temperature at cut-off is probably little above that of saturated steam.

European practice in this matter of lubrication is very different from American. Instead of a lubricator attached to the steam pipe above the throttle, and depending upon the hydrostatic pressure of condensed steam to force the oil into the pipe, a little pump, operated by a ratchet wheel driven from some reciprocating part of the valve gear, forces the oil through small tubes directly to the valves or other parts requiring it.

Experience has shown that, with engines of ordinary design using superheated steam, a temperature at the throttle of 475 degrees Fahr. should not be exceeded. How far the superheating can be safely carried with a given engine can be determined by experiment only, as it depends largely upon the construction. It often happens that a much lower temperature than 475 degrees is found advisable, but even then a considerable saving may be made in the operating expense. If the temperature becomes much higher, operation may become impossible on account of the difficulty in lubricating the working parts properly, or the expenditure for lubricants may be so great as to neutralize any advantage derived otherwise. The lubrication difficulty prevents the use of unbalanced slide valves with very high temperatures, and compels the application of poppet valves, or completely balanced piston valves.

As an example of the effect of differing degrees of superheat, three tests on a twenty horse-power non-condensing engine, mentioned by Carl Jacobi, may be quoted.* The steam pressure was about 100 pounds.

Temperature of Steam.	Steam Consumption in Pounds per Horse-power Hour.
464 deg. Fahr.	28
536 " "	22.5
662 " "	17.5

* Paper read to the Sachsischen Ingenieurverein D. Ing. und Sachsischen Electrotechn. Gesellschaft.

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To gain any advantage from the increase of volume the superheating should be carried to the highest degree practicable. Experience has shown that the steam should be heated 125 to 175 degrees above the saturation temperature, in order to prevent condensation before cut-off. Even in a non-conducting cylinder it would be impossible, with a high initial pressure, to preserve the steam in a superheated condition till the end of expansion. With lower pressures an initial temperature of 650 degrees is necessary in order, theoretically even, to permit of superheat in the exhaust. In the engine as actually constructed there are many disturbing elements. From one-quarter to one-half of the so-called dry steam entering the cylinder is condensed during admission, and the most of it goes out of the exhaust port without having performed any work. Under the best conditions an initial condensation of at least twenty per cent. is to be expected. There is frequently, during expansion, a partial reëvaporation of the steam condensed during admission, and tests on multiple-expansion engines, driven with saturated steam, and equipped with cylinder jackets and reheating receivers, have sometimes shown the steam to be slightly superheated at release in the low-pressure cylinder.

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As an example of the effect of differing degrees of superheat, three tests on a twenty horse-power non-condensing engine, mentioned by Carl Jacobi, may be quoted.* The steam pressure was about 100 pounds.

Temperature of Steam.	Steam Consumption in Pounds per Horse-power Hour.
464 deg. Fahr.	28
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For superheated steam the specific heat at constant pressure is about .4805, and for air it is .2375.

There is always a loss by radiation in the steam pipes and passages, as well as a loss due to clearance, and to the heat absorption by the cylinder walls, which are exposed periodically to the temperature of the exhaust. The advantage of superheated steam may be attributed to three considerations: at high temperature it behaves like a gas, and a considerable amount of heat may be abstracted before any portion will liquefy; a moderate addition of heat produces a proportionately large increase in volume, and diminishes the weight of steam used per stroke for a given amount of work; it has a greatly reduced thermal conductivity as compared with saturated steam, and therefore the heat absorbed by the cylinder walls becomes a fraction only of what it would otherwise be.

To gain any advantage from the increase of volume the superheating should be carried to the highest degree practicable. Experience has shown that the steam should be heated 125 to 175 degrees above the saturation temperature, in order to prevent condensation before cut-off. Even in a non-conducting cylinder it would be impossible, with a high initial pressure, to preserve the steam in a superheated condition till the end of expansion. With lower pressures an initial temperature of 650 degrees is necessary in order, theoretically even, to permit of superheat in the exhaust. In the engine as actually constructed there are many disturbing elements. From one-quarter to one-half of the so-called dry steam entering the cylinder is condensed during admission, and the most of it goes out of the exhaust port without having performed any work. Under the best conditions an initial condensation of at least twenty per cent. is to be expected. There is frequently, during expansion, a partial reëvaporation of the steam condensed during admission, and tests on multiple-expansion engines, driven with saturated steam, and equipped with cylinder jackets and reheating receivers, have sometimes shown the steam to be slightly superheated at release in the low-pressure cylinder.

Though the advantage to be derived from superheated steam was appreciated fifty or sixty years ago, the mechanical difficulties encountered stood in the way of its widespread adoption until within the past five or ten years. The danger of burning out the metallic surfaces, exposed to the high temperatures, had to be met, and while it cannot be eliminated, the fact that there are

thousands of such installations, both large and small, in every-day use at the present time, is good evidence that it has been minimized.

The use of high fire-test mineral oils for cylinder lubrication, and of metallic or asbestos packing, disposes of the other most serious questions. More careful and more plentiful lubrication is required unquestionably than with saturated steam, for the presence of condensed steam on the cylinder walls is an undoubted aid to their proper lubrication. The temperatures are not as high as those of gas-engine cylinders, and, in fact, unless the steam is highly superheated, the temperature at cut-off is probably little above that of saturated steam.

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The above comparison is rough, and unduly favorable to the tests run with the higher temperature, since the only true basis for comparison is the heat consumption. While a proportionate difference in the coal consumption would not appear, were it possible to give the figures, the fact should not be overlooked that a material reduction in the steam consumption means a corresponding cut in the required boiler capacity.

Some notion of the relative economy of different types of engines working with highly superheated or with saturated steam may be gained from the following table, given by Herr Jacobi, in which the respective thermal efficiencies are expressed:

ENGINES WORKING WITH

Saturated Steam.			Highly Superheated Steam.		
Type	Horse-power.	Thermal Efficiency. p. c.	Type	Horse-power.	Thermal Efficiency. p. c.
Simple non-condensing.....	30	6.7	Simple non-condensing.....	30	12.5
Simple condensing..	40	9.2	Simple condensing..	40	15.5
Compound condensing.....	150	13.3	Compound condensing.....	90	21.0
Triple ex. condensing.....	400	16.5	Compound condensing..... ...	250	22.0

Comparative tests to determine the relative economy of saturated and superheated steam have been run on many different types and sizes of engines, with varying degrees of superheat, during the past few years, by various well-known engineers. To refer to even a small percentage would take too much time, and would soon become monotonous. A net gain in economy of ten to fifteen per cent. is a common result, while a saving of twenty, twenty-five, and even thirty per cent. is by no means uncommon. Of course the largest saving is made with the more wasteful types of engines.

The most economical results thus far obtained have been secured with compound engines using superheated steam. The use of triple-expansion machines is thought by many designers to be inadvisable, because of increased initial expense, increased friction, increased oil consumption, care and complication, and inadaptation to fluctuating loads, to say nothing of jackets, reheaters, and space requirements.

A triple-expansion engine installed at the factory of Ed. Vaucher et Cie., of Mülhausen, was so arranged that it could be

operated as a triple, with superheated steam in the high-pressure cylinder, or as a compound engine with a reheating receiver, and using superheated steam, therefore, in both cylinders.* When operated as a compound machine there was a gain of 10.5 per cent. over the steam consumption, and 6 per cent. over the coal consumption, of the engine when operated as a triple, and a reduction in the indicated work from 746.5 horse-power to 727.2 horse-power, although the load carried under both conditions was kept the same.

Tests conducted by R. Doerfel on a vertical triple-expansion mill engine, in Zwodau, were reported in the *Zeitschrift des Vereines deutscher Ingenieure*, December 16, 1899. The cylinder sizes are approximately 23½ inches, 37½ inches, and 53 inches diameter, by 35½ inch stroke; the speed, 85½ revolutions per minute. The high-pressure cylinder has poppet valves, the intermediate and low, four rolling valves each, of the Corliss type, operated by wrist plates, but without any releasing gear. The high-pressure cylinder has a jacket which is traversed by the exhaust, and really constitutes the first receiver. This arrangement is thought to have no ill effect on the performance in the high-pressure cylinder, and to minimize the loss by external radiation. The intermediate and low-pressure cylinders are not jacketed, nor are special receivers provided.

Four tests were made, of four hours each, in April, 1898, with steam of 139 pounds boiler pressure, and superheated from 136 degrees to 153 degrees, corresponding to a temperature at the throttle of about 500 degrees Fahr. The steam consumption was between 10¾ and 11 pounds per horse-power per hour, and the heat consumption 13,572 to 13,866 British thermal units. The indicated rate of work ranged from 613 to 802 horse-power. After analyzing the results, the inference is drawn that with three-cylinder machines the influence of the high temperature is limited too closely to the high-pressure cylinder. The intermediate cylinder derives some slight benefit, and the low-pressure cylinder little or none.

It is common practice to omit the jacket from the high-pressure cylinder, but to retain it on the low, though some builders prefer to use a reheating receiver, and no steam jacket on either cylinder. Since the mission of the jacket is to reduce the initial

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condensation, it would seem useless to introduce it, with the extra complication and expense entailed, if the same result can as well be attained in another way.

In this connection a series of ten experiments reported by Doerfel* are of interest. They were conducted on a simple 18-inch x 36-inch Corliss engine, running 74 revolutions per minute, at a machine-shop in Karolinenthal, and developing from 30 to 50 horse-power. The engine ran condensing, with steam pressures ranging, on the different tests, from 7 to 17 pounds. The steam was heated 45 degrees to 255 degrees Fahr. above the saturation temperature, and the steam consumption diminished from 30.3 pounds per horse-power hour, with the lower temperature and pressure, to 20 pounds at the higher temperature and pressure. Expressed in terms of the heat consumption, the saving is, of course, not so marked, though upwards of 28 per cent. The heat consumption diminished from 35,160 British thermal units per horse-power hour, to 25,340 British thermal units.

Steam was used in the jackets during five of the tests, but so far as any visible effect is to be seen in the results, the jacket could be dispensed with. As the temperature of superheat increased, the heat consumption of the jacket diminished, being 1.5 per cent. of the total in the first test, and .5 per cent. in the last.

Judging from the results, a large saving can be effected in many old plants using compound engines, by superheating the receiver steam, even though it may not be possible to properly lubricate Corliss valves when using superheated steam under high pressure. The superheating could best be effected with highly superheated steam introduced into the heating coils of the receiver, and passing thence to the throttle valve.

Engines using this principle have been built in Bohemia. A compound engine, 29 inches and 48 inches by 52 inches, installed in a cotton factory in Schlan, in 1898, was tested in July of that year, and in the following January.† The engine is underloaded, cutting off at one-tenth stroke, runs 74 revolutions per minute, and develops 500 to 575 horse-power with steam of one hundred pounds boiler pressure. The high-pressure cylinder is jacketed, and the steam, heated to a temperature of 550 degrees Fahr., or thereabouts, passes through the heating coils of the receiver, and the high-pressure jacket, before reaching the steam chest. A test

* *Zeitschrift des Vereines deutscher Ingenieure*, December 9, 1899.

† Doerfel, *Zeits. d. Ver. deutscher Ing.*, December 9, 1899.

showed that the receiver steam, at two pounds pressure, was superheated by this arrangement 110 degrees, and the steam accounted for at cut-off by the low-pressure indicator card was 11.51 pounds, while the actual consumption of the engine was 11.84 pounds per horse-power per hour. In other words, the device neutralized almost completely the initial condensation in the low-pressure cylinder. The steam temperatures were, at the boiler, 594 degrees Fahr.; before the receiver heating coils, 540 degrees, and at the throttle, 405 degrees.

In the case of large engines, where the area of the cylinder walls, or the cooling surface, is small as compared with the volume of steam admitted, the walls might become so hot during a period of heavy load and late cut off as to render lubrication difficult. Accordingly, some engines have been built with a special valve under the control of the regulator, which, during periods of overload, admits steam from the main pipe to the heating coils of the receiver, and thus cools the steam before it reaches the throttle. An engine installed in Amsterdam, and tested by Professor Ewing, has the valve so arranged that it opens when the receiver pressure rises, that fact implying that a smaller part of the whole expansion is taking place in the high-pressure cylinder, that there is less need of superheat there, and that it is advantageous to transfer the excess to the low-pressure cylinder. For simple engines, saturated steam may be drawn directly from the boiler to mix with the superheated steam. In the extreme position of the regulator, equal quantities of saturated steam and of superheated steam are admitted, in the attempt to keep the packing rings always in a zone of saturated or of slightly superheated steam.

If superheated steam be used in an old pipe line, designed for saturated steam, there will be found a diminished difference in pressure between the two ends of the main, because a gas of much less density is handled, without entrained moisture and with less friction. With a speed of one hundred feet per second the loss in pressure will be no more than with a speed of sixty feet for wet steam. The larger the pipe, the greater the loss by radiation; the smaller the pipe, the greater the loss by throttling. The loss by radiation may be 1 degree Fahr. for 2 feet of pipe, but with good thick covering, a very high steam speed, and a correspondingly small radiating surface, the loss has been reduced to 1 degree for 6 linear feet of piping.

Either metallic or asbestos packing should be used for making

the joints in the pipe line. Kieselguhr, a porous infusorial earth, is an approved covering for the pipes, valves, and flanges, and should be applied liberally. The steam cylinder should be well protected also, since radiation there may have quite an effect, especially if, as in the more common type of Corliss engines, the cylinder ends around the steam valves are wholly unprotected. The increased temperature near the engine is quite noticeable when it is run with superheated steam.

The demand for condensing water is no greater than with saturated steam, and it may easily be less. A portion of the added heat is turned into work and if more heat per pound of steam goes out with the exhaust, since the steam consumption is diminished, the demand for cooling water should be no greater, and possibly no less.

The installation of a superheater is equivalent to an increase in boiler capacity, and enables intermittent loads, such as are imposed upon hoisting or rolling-mill engines, to be handled without danger of water being carried over to the engine cylinder when starting.

To describe even a considerable percentage of the many superheaters manufactured would lead to much wearisome repetition, and the attempt will therefore be made to point out the important requisities for any successful system, and to describe a few which may be regarded as typical, or as presenting particularly interesting features. Any given type is subject to numerous modifications, according to where it is to be placed, the kind of boiler to be equipped, the space available, the amount of superheat required, or other special conditions. A comparison of the settings shown for different water-tube boilers, and the plans devised for keeping the joints out of the fire, and for protecting the coils from overheating, by means of dampers, is quite interesting.

Almost any kind of superheater can be fired independently, or can be arranged in connection with the boiler flues, so as to dispense with the separate furnace. The latter arrangement is usually preferred, as it is found to be more economical, and the tubes can better be protected from the extreme heat of the fire-box. Where the engines are placed at a long distance from the boilers, an independent superheater becomes advisable. The first cost may be greater, but it need not entail a large expense for maintenance, because the furnace can be fired at intervals of

several hours, the fire left to burn slowly as in an ordinary stove, and a more even temperature maintained. The space required is small, and repairs can easily be made if a suitable by-pass is provided, without in any way hindering the operation of the rest of the plant.

If the coils are placed directly in the boiler flues, without dampers by means of which they may be protected from the hot gases, while the boiler is being warmed before steam is generated, provision is generally made for flooding them with water. With bad feed water this introduces the difficulty with mud or scale which must be guarded against, or a careless manipulation of the valves may cause a dangerous water hammer. It is, therefore, better practice to dispose the superheater so that it can be protected at such times by dampers, and be subjected to the action internally of steam alone.

Cast-iron superheaters have the advantage that they can stand, without injury, any temperature to which they are likely to be exposed, when properly placed. They are so much heavier and thicker than wrought iron, besides being ribbed after the fashion of a gas-engine cylinder, that they require a higher heat for the same useful effect, but, at the same time, serve as reservoirs of heat, and tend to equalize the temperature of the steam in spite of wide variations in the furnace temperature. They must be accessible so that the soot can easily be blown from the ribbed surfaces. The use of cast-iron for such a purpose introduces a certain element of danger, though perhaps inconsiderable, on account of the porosity of castings in general, and the particular likelihood of spongy places occurring in ribbed castings.

If the superheater were placed in the chimney, or in the main flue leading to it, too high a temperature of the flue gases would be required for an economical utilization of the heat. If the gases went off at a moderate temperature, 350 degrees to 500 degrees, the temperature of superheating attained would be so low as to be of little value. If placed too near the fire, the superheating coils could not withstand the heat. Hence an intermediate position must be chosen, where the gases have lost some of their heat, but may yet give up more to the water-heating surface.

The requirements for a successful superheater are:

First, security in operation, or a minimum danger of overheating.

Second, economical use of heat applied.

Third, no exposure of joints to the fire.

Fourth, provision for free expansion.

Fifth, disposition such that it may be cut out, or repaired, without interfering with the operation of the plant.

Sixth, ease of application to existing plants.

The tube elements may be arranged either in series or in parallel. In parallel, a small quantity of steam passes through each small tube, as in the Gehre type. The relatively large heating surface, and small area of cross section, combined with the low heat conductivity of the steam, makes this arrangement seem well conceived. In series, as in the Schwoerer, the cross section of the heating coil must be larger, and the steam speed higher. The high velocity of flow would seem to be effective, as it enhances the whirling or eddying effect at turns or bends, causes a better mixture of the current, and gives a better chance for the whole body to come in contact with the heating surface. As yet it is impossible to decide which method is best, but it is conceded that if the volume is very large, and the superheating surface small, only the exterior portion of the current will be acted upon. Steam speeds through the coils are taken all the way from sixty feet to one hundred and sixty feet per second.

It is an interesting fact that neither cast iron nor steel lose in tensile strength when subjected to the temperature of superheated steam, but, on the contrary, may be stronger. Tests made at the Watertown arsenal, and summarized by Professor Lanza, showed that the tensile strength of steel diminishes as the temperature increases from 0 degree Fahr., until a minimum is reached between 200 and 300 degrees, mild steel reaching the place of minimum strength at lower temperatures than higher carbon steels. From this point they display greater tenacity, increasing sometimes as much as twenty-five per cent., as the temperature increases, until a maximum is attained somewhere between 400 and 650 degrees. While high-carbon steels reach the temperature of maximum strength abruptly, and retain it over a limited range of temperature, mild steels, such as would be used for superheater tubes, retain the increased tenacity over a wider range.

Cast iron appeared to maintain its strength with a tendency to increase until 900 degrees Fahr. was reached, beyond which the strength diminished. A few tests recently reported by Bach showed a practically constant strength up to 570 degrees, and thereafter a steady drop. At 750 degrees there was a loss of

eight per cent. of the tensile strength at ordinary temperatures.

The Schmidt system of utilizing superheated steam, which is referred to frequently as resulting in the highest efficiency yet attained with the steam engine, is designed especially to attain the theoretical gain due to a high initial temperature, a temperature which is impracticable with the ordinary engine. The steam is heated to 660 degrees Fahr., and an engine of a special type is built to use it.

The illustration (Fig. 362) shows a boiler with feed-water heater, economizer, and superheater as built under the Schmidt patents by the Aschersleben Maschinenbau A. G. The economizer consists of eight tiers containing five coils each of spirally-wound 2-inch pipe. Directly above are eight tiers containing four coils each of $2\frac{3}{4}$-inch pipe constituting the superheater. Placed on a higher level is the feed-water heater, which is a simple cylindrical vessel containing a coil of pipe. The feed water enters the heater at the bottom, and is discharged by a pipe near the top into the boiler. The lower end of the heater coil is connected with the lower end of the economizer coil, and the upper ends are also connected together, and to the steam space in the boiler.

Steam entering the heater coil is condensed, imparting its heat to the surrounding water, and then, flowing to the economizer, it is re-evaporated and returned to the top of the heater coil to repeat the cycle indefinitely. The use of distilled water in this manner obviates the danger of the economizer becoming filled with mud or scale, and the heater is of such a form as to be readily accessible and easily cleaned. A feed-water temperature of 260 degrees, equivalent to a boiler pressure of 20 pounds, may be attained under favorable conditions.

The economizer and superheater are arranged with a view to using the heat of the gases completely, and, by a combination of a parallel and a countercurrent flow of the steam through the superheater, to protect it from destruction by the hottest gases. The path of the gases of combustion is downward, first through the superheater, and then through the economizer, leaving the latter at a temperature of 350 degrees to 400 degrees Fahr. To use the countercurrent principle as far as desirable, the wet steam enters the lower part of the superheated coil and flows upward through four tiers. Should the countercurrent principle alone be applied, an economical use of the gases would be assured, but that

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In this connection a series of ten experiments reported by Doerfel* are of interest. They were conducted on a simple 18-inch x 36-inch Corliss engine, running 74 revolutions per minute, at a machine-shop in Karolinenthal, and developing from 30 to 50 horse-power. The engine ran condensing, with steam pressures ranging, on the different tests, from 7 to 17 pounds. The steam was heated 45 degrees to 255 degrees Fahr. above the saturation temperature, and the steam consumption diminished from 30.3 pounds per horse-power hour, with the lower temperature and pressure, to 20 pounds at the higher temperature and pressure. Expressed in terms of the heat consumption, the saving is, of course, not so marked, though upwards of 28 per cent. The heat consumption diminished from 35,160 British thermal units per horse-power hour, to 25,340 British thermal units.

Steam was used in the jackets during five of the tests, but so far as any visible effect is to be seen in the results, the jacket could be dispensed with. As the temperature of superheat increased, the heat consumption of the jacket diminished, being 1.5 per cent. of the total in the first test, and .5 per cent. in the last.

Judging from the results, a large saving can be effected in many old plants using compound engines, by superheating the receiver steam, even though it may not be possible to properly lubricate Corliss valves when using superheated steam under high pressure. The superheating could best be effected with highly superheated steam introduced into the heating coils of the receiver, and passing thence to the throttle valve.

Engines using this principle have been built in Bohemia. A compound engine, 29 inches and 48 inches by 52 inches, installed in a cotton factory in Schlan, in 1898, was tested in July of that year, and in the following January.† The engine is underloaded, cutting off at one-tenth stroke, runs 74 revolutions per minute, and develops 500 to 575 horse-power with steam of one hundred pounds boiler pressure. The high-pressure cylinder is jacketed, and the steam, heated to a temperature of 550 degrees Fahr., or thereabouts, passes through the heating coils of the receiver, and the high-pressure jacket, before reaching the steam chest. A test

* *Zeitschrift des Vereines deutscher Ingenieure*, December 9, 1899.

† Doerfel, *Zeits. d. Ver. deutscher Ing.*, December 9, 1899.

showed that the receiver steam, at two pounds pressure, was superheated by this arrangement 110 degrees, and the steam accounted for at cut-off by the low-pressure indicator card was 11.51 pounds, while the actual consumption of the engine was 11.84 pounds per horse-power per hour. In other words, the device neutralized almost completely the initial condensation in the low-pressure cylinder. The steam temperatures were, at the boiler, 594 degrees Fahr.; before the receiver heating coils, 540 degrees, and at the throttle, 405 degrees.

In the case of large engines, where the area of the cylinder walls, or the cooling surface, is small as compared with the volume of steam admitted, the walls might become so hot during a period of heavy load and late cut off as to render lubrication difficult. Accordingly, some engines have been built with a special valve under the control of the regulator, which, during periods of overload, admits steam from the main pipe to the heating coils of the receiver, and thus cools the steam before it reaches the throttle. An engine installed in Amsterdam, and tested by Professor Ewing, has the valve so arranged that it opens when the receiver pressure rises, that fact implying that a smaller part of the whole expansion is taking place in the high-pressure cylinder, that there is less need of superheat there, and that it is advantageous to transfer the excess to the low-pressure cylinder. For simple engines, saturated steam may be drawn directly from the boiler to mix with the superheated steam. In the extreme position of the regulator, equal quantities of saturated steam and of superheated steam are admitted, in the attempt to keep the packing rings always in a zone of saturated or of slightly superheated steam.

If superheated steam be used in an old pipe line, designed for saturated steam, there will be found a diminished difference in pressure between the two ends of the main, because a gas of much less density is handled, without entrained moisture and with less friction. With a speed of one hundred feet per second the loss in pressure will be no more than with a speed of sixty feet for wet steam. The larger the pipe, the greater the loss by radiation; the smaller the pipe, the greater the loss by throttling. The loss by radiation may be 1 degree Fahr. for 2 feet of pipe, but with good thick covering, a very high steam speed, and a correspondingly small radiating surface, the loss has been reduced to 1 degree for 6 linear feet of piping.

Either metallic or asbestos packing should be used for making

the joints in the pipe line. Asbestos, a porous infusorial earth, is employed covering for the pipes, valves, and flanges, and works as well as any. The steam cylinder should be well protected, and a steam jacket may have quite an effect, especially as in the more common type of Corliss engines, the cylinder ends around the steam valves are wholly unprotected. The increase in temperature near the engine is quite noticeable when working with superheated steam.

The demand for condensing water is no greater than with saturated steam, and it may easily be less. A portion of the added heat is turned into work and if more heat per pound of steam goes out with the exhaust, since the steam consumption is less, the demand for cooling water should be no greater, and may be less.

The installation of a superheater is equivalent to an increase in boiler capacity, and enables intermittent loads, such as are imposed upon hoisting or rolling-mill engines, to be handled without danger of water being carried over to the engine cylinder when started up.

To cover even a considerable percentage of the many superheaters manufactured would lead to much wearisome repetition, and the attempt will therefore be made to point out the important requisites for any successful system, and to describe a few which may be regarded as typical, or as presenting particularly interesting features. Any given type is subject to numerous modifications, according to where it is to be placed, the kind of boiler to be equipped, the space available, the amount of superheat required, or other special conditions. A comparison of the settings shown for different water-tube boilers, and the plans devised for keeping the joints out of the fire, and for protecting the coils from overheating, by means of dampers, is quite interesting.

Almost any kind of superheater can be fired independently, or can be arranged in connection with the boiler flues, so as to dispense with the separate furnace. The latter arrangement is usually preferred, as it is found to be more economical, and the tubes can better be protected from the extreme heat of the fire-box. Where the engines are placed at a long distance from the boilers, an independent superheater becomes advisable. The first cost may be greater, but it need not entail a large expense for maintenance, because the furnace can be fired at intervals of

several hours, the fire left to burn slowly as in an ordinary stove, and a more even temperature maintained. The space required is small, and repairs can easily be made if a suitable by-pass is provided, without in any way hindering the operation of the rest of the plant.

If the coils are placed directly in the boiler flues, without dampers, by means of which they may be protected from the hot gases, while the boiler is being warmed before steam is generated, provision is generally made for flooding them with water. With bad feed water this introduces the difficulty with mud or scale which must be guarded against, or a careless manipulation of the valves may cause a dangerous water hammer. It is, therefore, better practice to dispose the superheater so that it can be protected at such times by dampers, and be subjected to the action internally of steam alone.

Cast-iron superheaters have the advantage that they can stand, without injury, any temperature to which they are likely to be exposed, when properly placed. They are so much heavier and thicker than wrought iron, besides being ribbed after the fashion of a gas-engine cylinder, that they require a higher heat for the same useful effect, but, at the same time, serve as reservoirs of heat, and tend to equalize the temperature of the steam in spite of wide variations in the furnace temperature. They must be accessible so that the soot can easily be blown from the ribbed surfaces. The use of cast-iron for such a purpose introduces a certain element of danger, though perhaps inconsiderable, on account of the porosity of castings in general, and the particular likelihood of spongy places occurring in ribbed castings.

If the superheater were placed in the chimney, or in the main flue leading to it, too high a temperature of the flue gases would be required for an economical utilization of the heat. If the gases went off at a moderate temperature, 350 degrees to 500 degrees, the temperature of superheating attained would be so low as to be of little value. If placed too near the fire, the superheating coils could not withstand the heat. Hence an intermediate position must be chosen, where the gases have lost some of their heat, but may yet give up more to the water-heating surface.

The requirements for a successful superheater are:

First, security in operation, or a minimum danger of overheating.

Second, economical use of heat applied.

Third, no exposure of joints to the fire.

Fourth, provision for free expansion.

Fifth, disposition such that it may be cut out, or repaired, without interfering with the operation of the plant.

Sixth, ease of application to existing plants.

The tube elements may be arranged either in series or in parallel. In parallel, a small quantity of steam passes through each small tube, as in the Gehre type. The relatively large heating surface, and small area of cross section, combined with the low heat conductivity of the steam, makes this arrangement seem well conceived. In series, as in the Schwoerer, the cross section of the heating coil must be larger, and the steam speed higher. The high velocity of flow would seem to be effective, as it enhances the whirling or eddying effect at turns or bends, causes a better mixture of the current, and gives a better chance for the whole body to come in contact with the heating surface. As yet it is impossible to decide which method is best, but it is conceded that if the volume is very large, and the superheating surface small, only the exterior portion of the current will be acted upon. Steam speeds through the coils are taken all the way from sixty feet to one hundred and sixty feet per second.

It is an interesting fact that neither cast iron nor steel lose in tensile strength when subjected to the temperature of superheated steam, but, on the contrary, may be stronger. Tests made at the Watertown arsenal, and summarized by Professor Lanza, showed that the tensile strength of steel diminishes as the temperature increases from 0 degree Fahr., until a minimum is reached between 200 and 300 degrees, mild steel reaching the place of minimum strength at lower temperatures than higher carbon steels. From this point they display greater tenacity, increasing sometimes as much as twenty-five per cent., as the temperature increases, until a maximum is attained somewhere between 400 and 650 degrees. While high-carbon steels reach the temperature of maximum strength abruptly, and retain it over a limited range of temperature, mild steels, such as would be used for superheater tubes, retain the increased tenacity over a wider range.

Cast iron appeared to maintain its strength with a tendency to increase until 900 degrees Fahr. was reached, beyond which the strength diminished. A few tests recently reported by Bach showed a practically constant strength up to 570 degrees, and thereafter a steady drop. At 750 degrees there was a loss of

eight per cent. of the tensile strength at ordinary temperatures.

The Schmidt system of utilizing superheated steam, which is referred to frequently as resulting in the highest efficiency yet attained with the steam engine, is designed especially to attain the theoretical gain due to a high initial temperature, a temperature which is impracticable with the ordinary engine. The steam is heated to 660 degrees Fahr., and an engine of a special type is built to use it.

The illustration (Fig. 362) shows a boiler with feed-water heater, economizer, and superheater as built under the Schmidt patents by the Aschersleben Maschinenbau A. G. The economizer consists of eight tiers containing five coils each of spirally-wound 2-inch pipe. Directly above are eight tiers containing four coils each of $2\frac{3}{4}$-inch pipe constituting the superheater. Placed on a higher level is the feed-water heater, which is a simple cylindrical vessel containing a coil of pipe. The feed water enters the heater at the bottom, and is discharged by a pipe near the top into the boiler. The lower end of the heater coil is connected with the lower end of the economizer coil, and the upper ends are also connected together, and to the steam space in the boiler.

Steam entering the heater coil is condensed, imparting its heat to the surrounding water, and then, flowing to the economizer, it is re-ëvaporated and returned to the top of the heater coil to repeat the cycle indefinitely. The use of distilled water in this manner obviates the danger of the economizer becoming filled with mud or scale, and the heater is of such a form as to be readily accessible and easily cleaned. A feed-water temperature of 260 degrees, equivalent to a boiler pressure of 20 pounds, may be attained under favorable conditions.

The economizer and superheater are arranged with a view to using the heat of the gases completely, and, by a combination of a parallel and a countercurrent flow of the steam through the superheater, to protect it from destruction by the hottest gases. The path of the gases of combustion is downward, first through the superheater, and then through the economizer, leaving the latter at a temperature of 350 degrees to 400 degrees Fahr. To use the countercurrent principle as far as desirable, the wet steam enters the lower part of the superheated coil and flows upward through four tiers. Should the countercurrent principle alone be applied, an economical use of the gases would be assured, but that

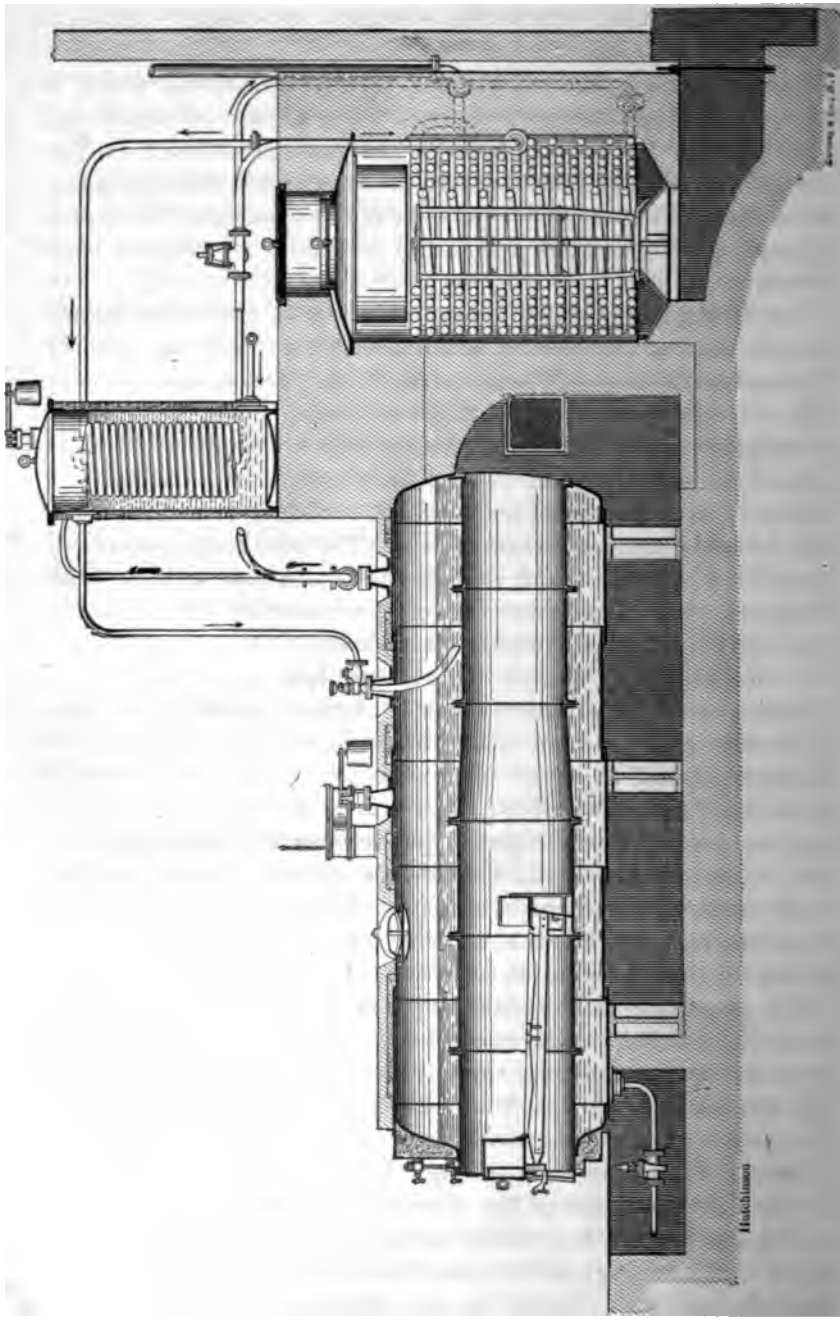


FIG. 362.

part of the superheater which was in contact alike with the hottest gases and the hottest steam would deteriorate rapidly. Accordingly, the steam is led from the fourth tier to the eighth, or upper tier, and passing down parallel to the flow of the gases is withdrawn from the fifth tier. The steam, dried in the lower coils, is supposed to reach the upper tier in this condition and become superheated by the hottest gases, which are just entering the apparatus. The degree of superheat can be controlled by dampers regulating the flow of the gases of combustion, that portion not passing through the coils being applied to the boiler heating surface.

The Schmidt Tandem-Heissdampfmaschine, as built at Aschersleben, is shown in Fig. 363. The engine is nominally single-acting with the high-pressure cylinder behind. The high-pressure and low-pressure pistons are cast in one piece, which is hollow. The space at the rear of the large piston, encircling the small trunk piston, constitutes the low-pressure cylinder, while the jacket on the large cylinder and the space in front of the piston, together with the piston's hollow interior, form a receiver with a varying volume. During the inward stroke the steam in this receiver expands and does some work, so that the engine in reality is double-acting. Poppet valves are used. This construction requires a single stuffing-box, which is exposed to low-pressure steam only, and the hollow piston forming part of the receiver is kept comparatively cool, while any heat transferred is not lost but taken up by the low-pressure steam.

Simple engines built after the Schmidt design are single acting, and therefore have no stuffing-box. The trunk pistons are made very long, and the packing rings placed well forward, so that for much of the stroke they are in contact with a portion of the cylinder which is exposed to the atmosphere during part of each revolution. They never reach that part of the cylinder which is exposed to the highest steam temperature. Cross compound engines, to use steam at such high temperatures, are built with single-acting, high-pressure cylinders, and are made double acting on the low-pressure side, since all of the superheat disappears in the first cylinder.

Engines and superheaters are built under the Schmidt patents by several concerns, and, of course, there is considerable variation in the design. Balanced piston valves are used instead of poppet valves, and vertical boilers with a provision for controlling the degree of superheat by admitting to the superheater coil con-

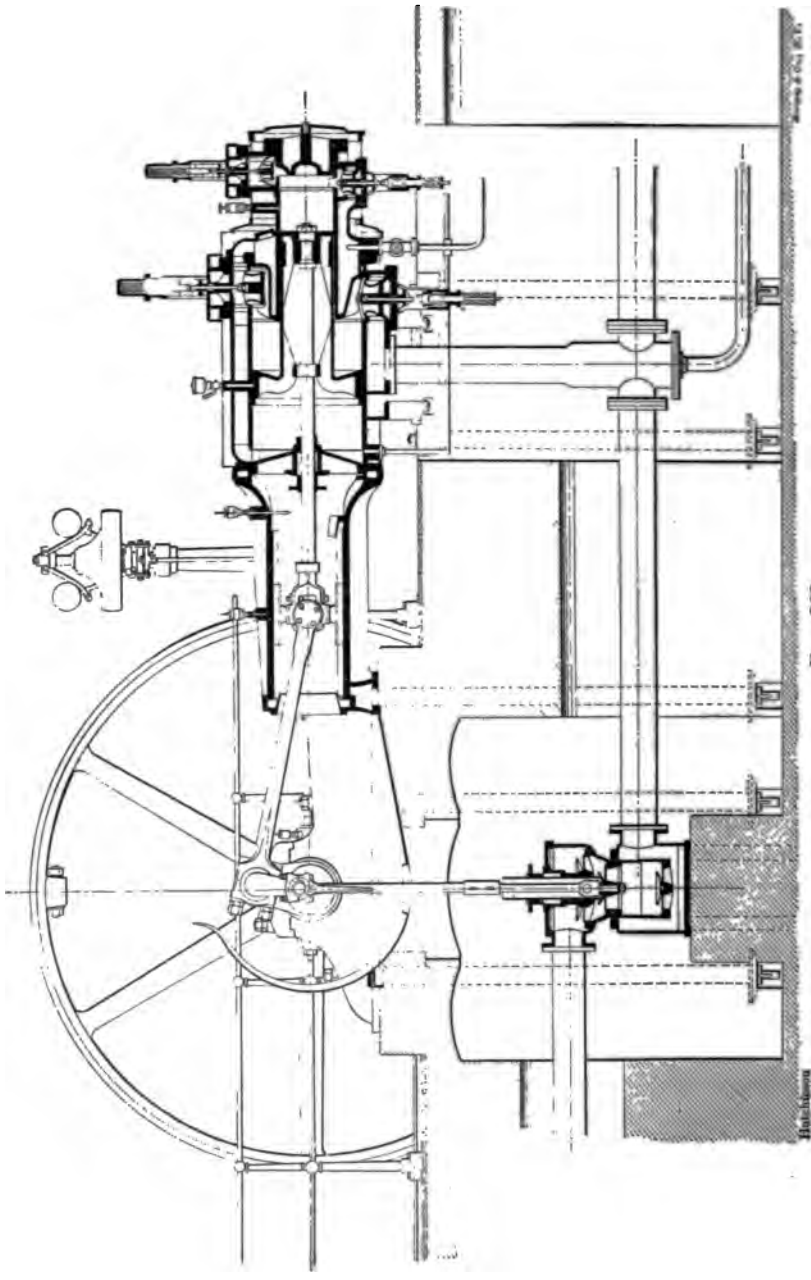


FIG. 808.

ed steam from the coil in the feed-water heater. These boilers
very low ratios of water-heating surface to grate surface,
in some cases the evaporation is as high as 10 pounds of
er per square foot of heating surface per hour. Very wet
m is wanted to protect the superheater.

few results from numerous tests on Schmidt engines have been
lated,* and are here presented (Table I.) in English units.
t of the tests were made on small engines, but Schmidt engines
in use which are developing 1,000 horse-power and more.

ome results of tests on a 3,000 horse-power, four-cylinder,
ical, triple-expansion Sulzer engine, using steam from Schmidt
pendently fired superheaters, are also summarized here for
venient reference.†

Tests Using Steam	Highly Superheated.			Moderately Superheated.	Saturated.	
pressure in pounds olute)	196.8	199.9	193.4	199.9	202.8	202.8
l pressure in high-pres- cylinder (absolute)	187.3	195.5	188.4	190.3	194.6	195.9
erature of steam in valve st	582	585	614	531	381	381
indicated horse-power	2,900	2,779	2,868	2,850	2,951	2,999
ds of steam per horse- er hour	9.64	9.67	9.56	10.29	11.77	11.75
hours per pound of coal.	477	482	479	447	438	435

he arrangement of the coils in the Hering superheater is shown
Fig. 364. The tubes are small in diameter and long, and are
le of Swedish iron without welds. Ordinarily steam tem-
ıtures of 450 degrees to 550 degrees are attained, though
peratures as high as 800 degrees can be used. Figs. 365 and
show the superheater as applied to an elephant boiler. The
gases leaving the grate heat the lower side of the mud drums,
ı pass up around the boiler shell near the rear end into the
erheater, thence down around the front portion of the boiler
l, and return back through the fire tubes to the chimney. The
wing shows an arrangement of dampers by means of which the
of gases can be controlled completely, or shut off altogether
n the superheater, in which case they will be applied as
nomically to the water-heating surface as though no super-
ter were present.

). Herre, "Die Anwendung des Überhitzten Dampfes im Dampfmaschinen-
ebe."
Zeitschrift des Vereines deutscher Ingenieure, 1899, No. 44, and 1900, No.
lso *Engineering Record*, October 13, 1900.

at New-Oberhausen. Thin wrought-iron tubes are used. The location of the baffle plates is clearly shown, and indicates that the gases make four passes over the water tubes. Steam from the drum above flows down through the pipe at the side, and a portion is drawn through the six U-shaped tubes which the gases encounter after their first pass through the water tubes. Another portion of the steam goes through the bank of five tubes beyond. The entrained water and the remainder of the steam circulate through the last bank of twelve tubes, where more heating surface is given

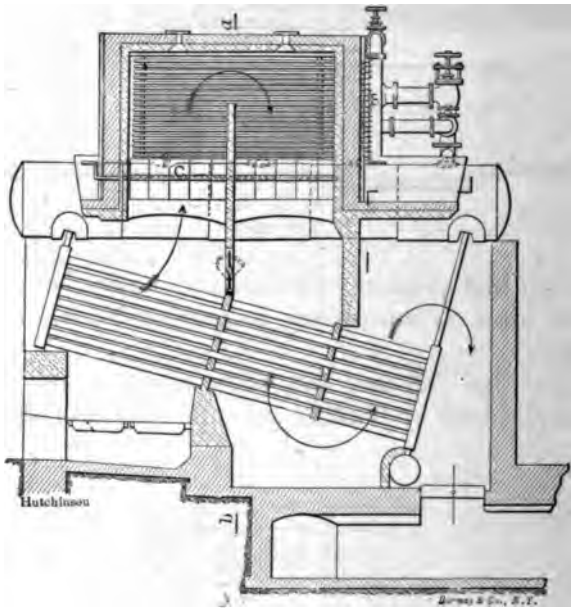


FIG. 367.

than in the preceding groups, because this series of tubes is exposed to cooler gases. The superheated steam is withdrawn from the three groups as shown by the pipe dotted in the side elevation. In this case the steam divides into three portions, each of which traverses throughout its whole length a group of pipes forming one section of the superheater.

The Gehre superheater, as adapted to a water-tube boiler, is shown in Fig. 370. The boiler in question is built by the Rather Röhrenkesselfabrik, and has its water legs made of sheet steel stayed with channel irons riveted between each tier of water tubes. Through each channel project, above and below, a series of nipples,

the whole being contrived so as to form at the end of each row of tubes a small water chamber, with a steam pocket above. The nipples make free communication between these steam pockets, so that steam generated in any tier of tubes can easily reach the steam drum above without meeting any obstruction.

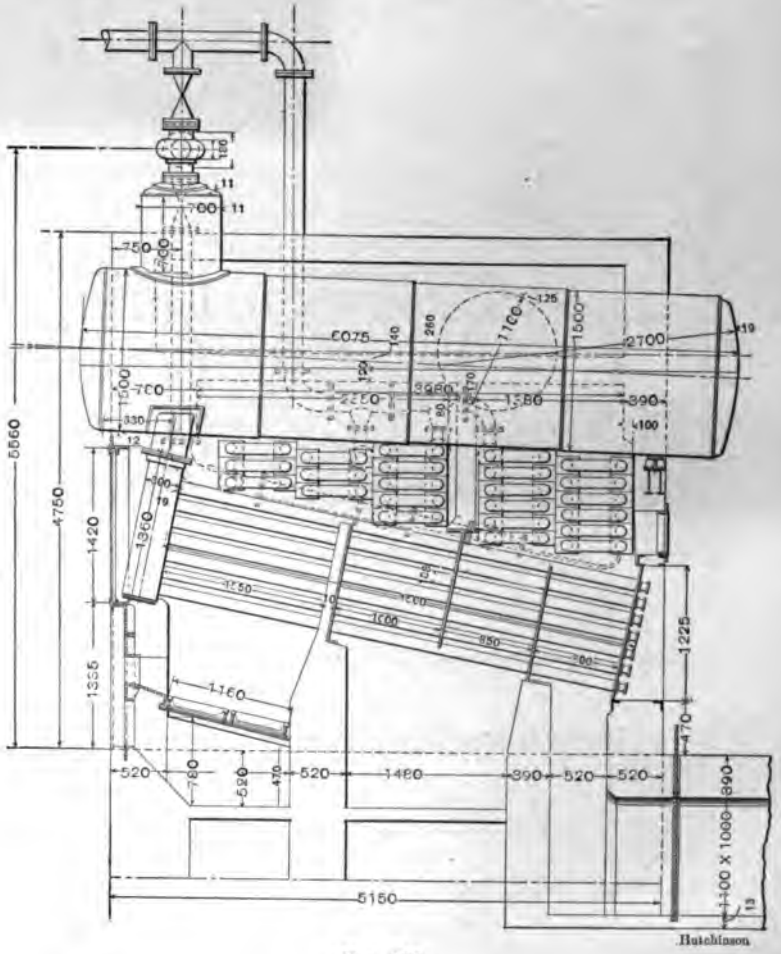
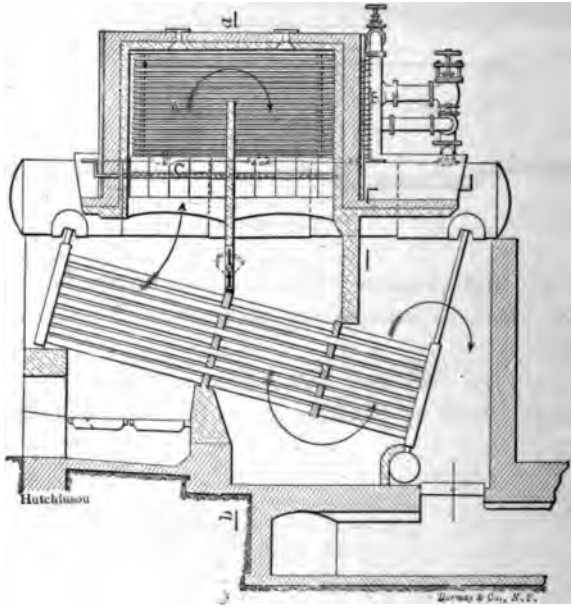


FIG. 368.

A row of water tubes is omitted, and sleeves, carried through the water legs, allow three or four small superheating tubes to pass through each sleeve into headers outside, thus removing all joints from the fire. Wet steam enters the front header, and superheated steam is withdrawn from the rear. If a high degree

at New-Oberhausen. Thin wrought-iron tubes are used. The location of the baffle plates is clearly shown, and indicates that the gases make four passes over the water tubes. Steam from the drum above flows down through the pipe at the side, and a portion is drawn through the six U-shaped tubes which the gases encounter after their first pass through the water tubes. Another portion of the steam goes through the bank of five tubes beyond. The entrained water and the remainder of the steam circulate through the last bank of twelve tubes, where more heating surface is given



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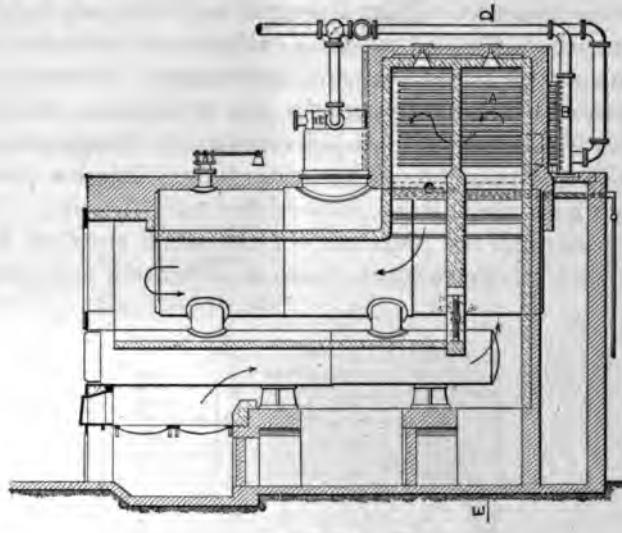

FIG. 365.

entering the high-pressure cylinder, and again, before entering the low, as much as is necessary to prevent condensation during admission.

The cuts, Figs. 368 and 369, show a water-tube boiler with superheater, as built by Walther & Co. for the Gutehoffnungshütte

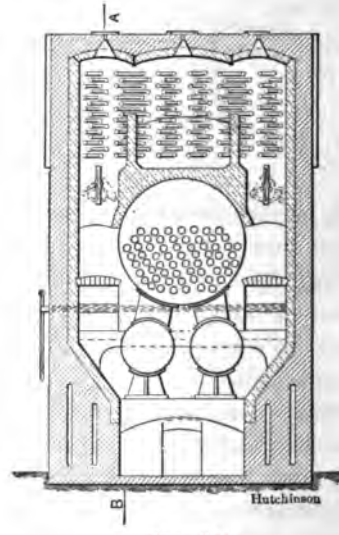

FIG. 366.

of superheat is desired, two tiers of superheating tubes are put in, so that the steam makes a double pass.

With the ordinary horizontal fire-tube boiler, a series of coils is placed in the combustion chamber at the rear, so that the gases pass over them before entering the flues which lead to the uptake.

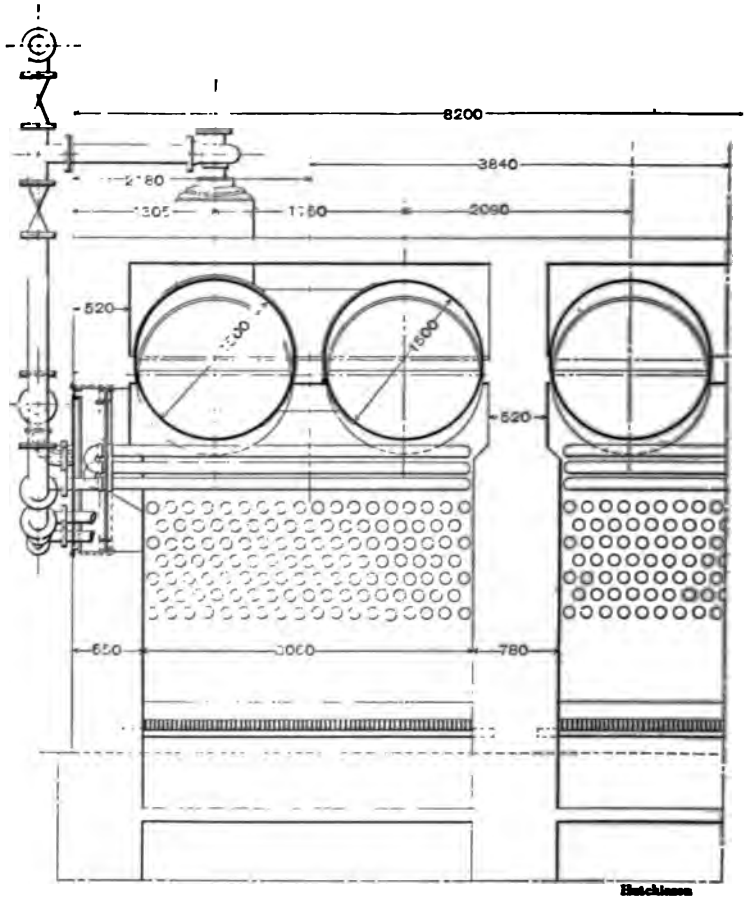

Fig. 369.

In either type provision is made for flooding the superheater with water. Temperatures of 180 degrees to 270 degrees above the saturation temperatures are usually attained.

The Gehre superheater formerly was a cylindrical shell filled with fire tubes, like a miniature cylindrical boiler without any steam space. It could not be exposed to very high temperatures,

and was in fact a good steam dryer if the flue temperatures were fairly high.

The Steinmüller superheater is made up of a series of U-tubes, $1\frac{5}{16}$ inches internal diameter, which terminate in a two-compartment header placed at the back of the boiler, between the steam

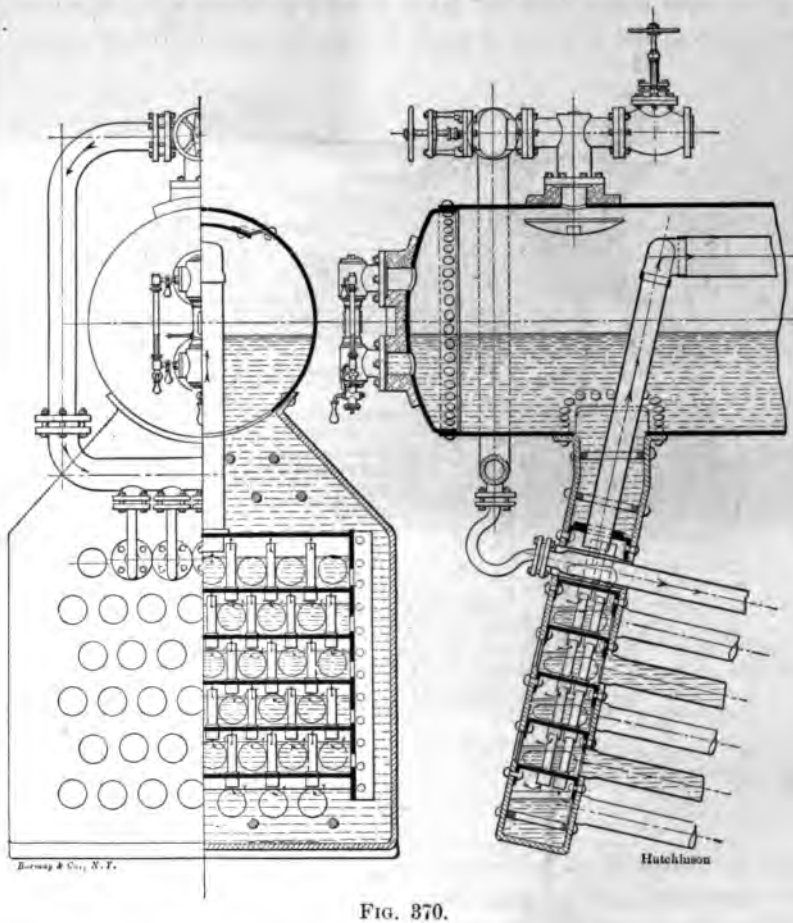

FIG. 370.

drum and the water tubes (Fig. 371). The gases reach the superheater after making a single pass through the water tubes. Brick arches and dampers are so placed that the superheating tubes can be isolated from the flue gases if necessary.

In the header there are openings provided with suitable screw plugs (Fig. 372) in the outer wall opposite the tube ends. The plugs for that compartment which the wet steam enters are pro-

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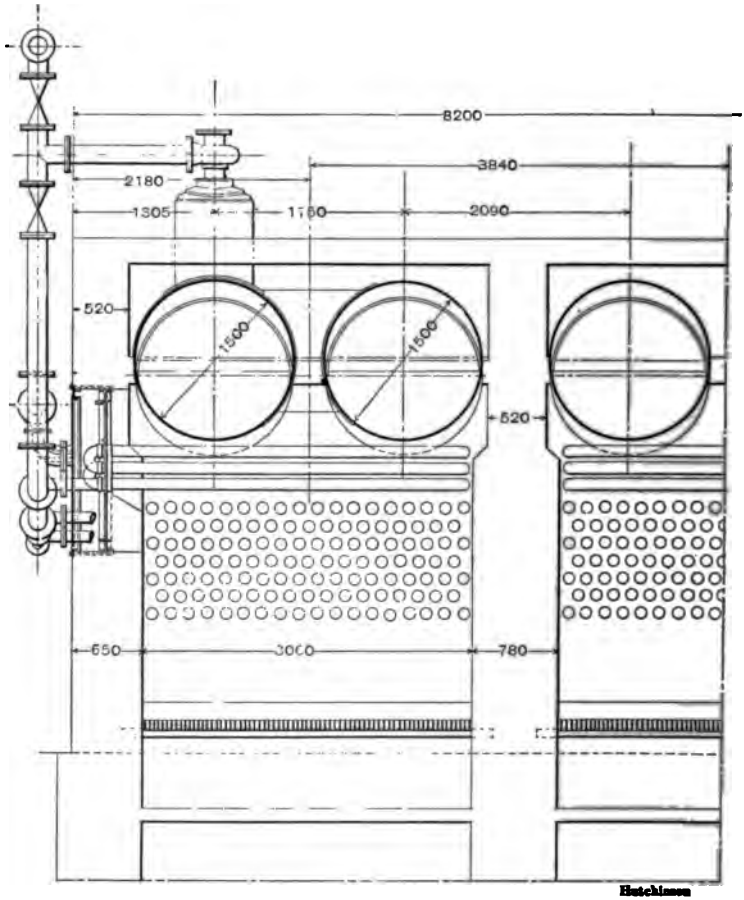

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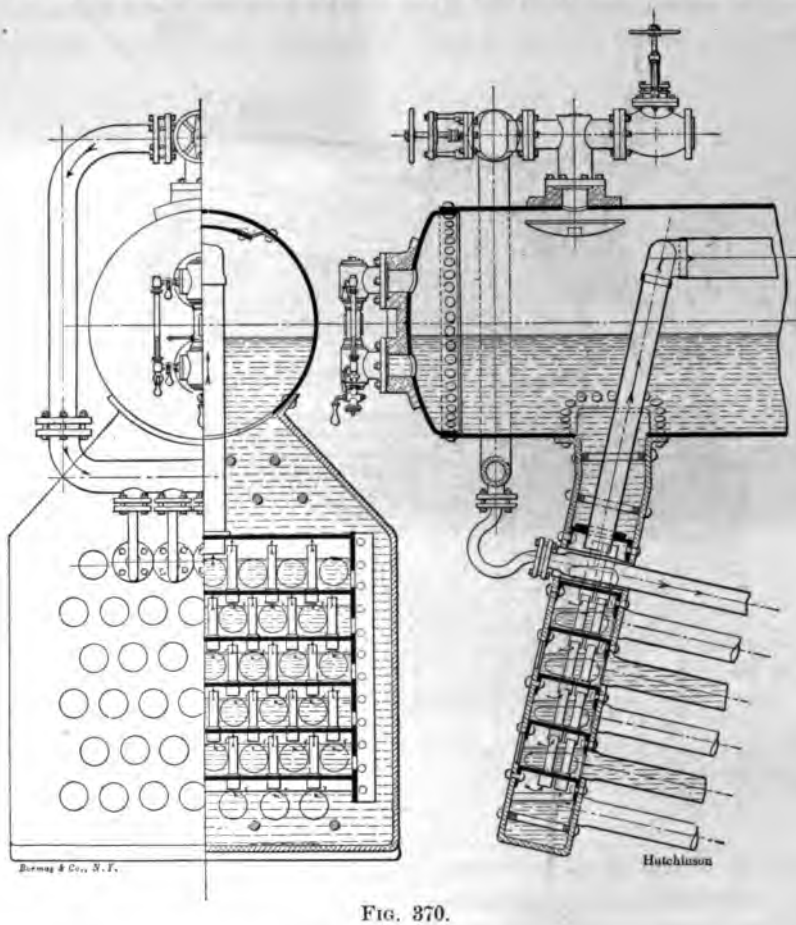

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In the header there are openings provided with suitable screw plugs (Fig. 372) in the outer wall opposite the tube ends. The plugs for that compartment which the wet steam enters are pro-

veled with stems bearing little disks which serve to choke the entrance to the superheating tubes, retard the flow, prevent short circuiting and increase the heat absorption of a given weight of steam without increasing the heating surface unnecessarily. The discharge end of the U-tube is left unrestricted.

The superheater built by Hans Reisert presents novel features, inasmuch as the attempt is made to equalize the degree of super-

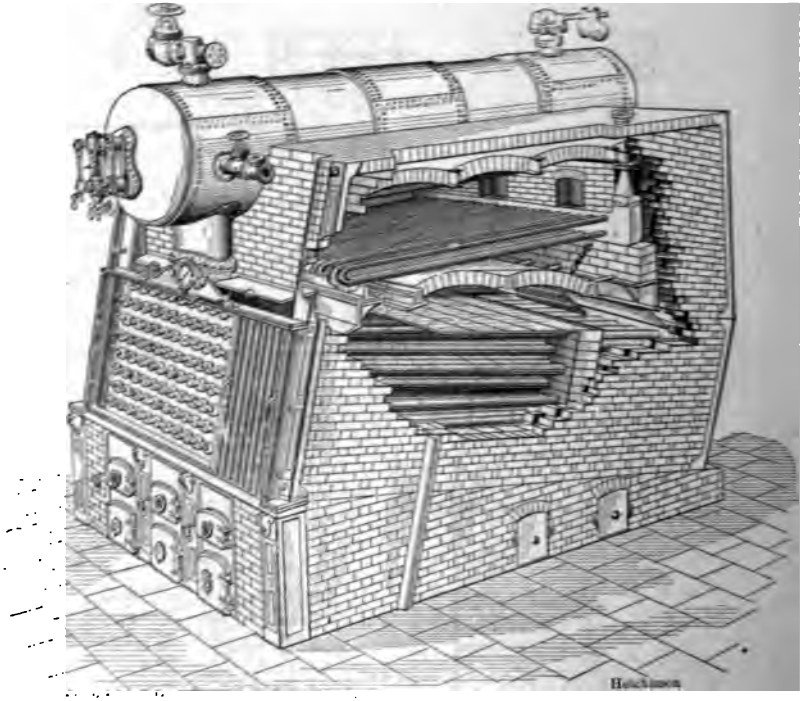
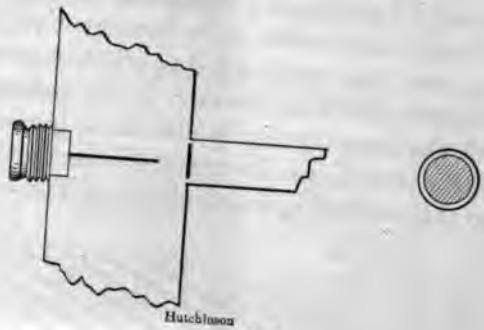


Fig. 371.

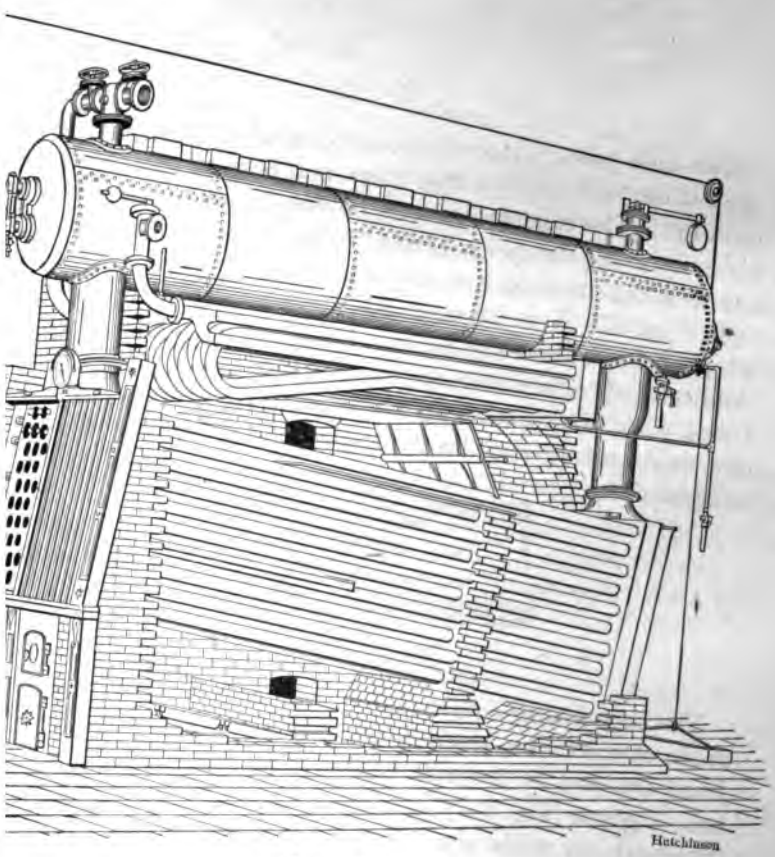
heat by means of an increasing velocity of flow of steam through the apparatus, and by a special provision for mixing the current.

The superheating tubes are placed, as shown in the cut, Fig. 373, much as in the Steinmüller and many other makes. The important difference is found in the header shown in Fig. 374. The wet steam enters at A, flows through the U-tubes 1, 1^1, 2, 2^1, and 3, 3^1 back to the hood K^1, thence through 4, 4^1 and 5, 5^1 to K_2, then through 6, 6^1 and 7, 7^1 to K_3, through 8, 8^1 to K_4, next through 9, 9^1 to B, and from B out to the engine. The hoods K_1, K_2, K_3 and K_4 have the wet steam on the outside, and the superheated on the



Hutchinson

FIG. 372.



Hutchinson

FIG. 373.

inside, so that there is no pressure difference. It appears that the steam flows through three tubes, then through two, and finally through one, so that, if its initial speed is fifty feet per second, the speed rises to seventy-five feet, and then to one hundred and fifty, increasing with the superheating temperature, because, as it becomes more like a perfect gas, the frictional loss diminishes.

To facilitate the mixture, a device, shown in Fig. 375, is placed

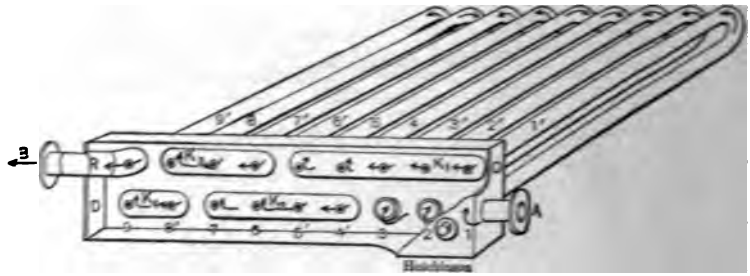


FIG. 374.

within each tube, to turn the cooler central portion of the current against the wall and the hotter external portion into the centre of the tube. The superheater can be filled with water in case of necessity, and a damper is located so that more or less of the gases can be short-circuited, and the temperature thus regulated.

In Fig. 376 is to be seen the arrangement of a superheater adopted for water-tube boilers by B. Meyer. It is placed in duplicate at either side of the steam drum, above the water tubes, with brick arches so placed that, by the use of dampers, the superheating can be controlled, or the apparatus cut out altogether.

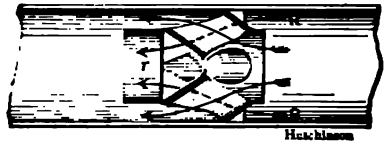


FIG. 375.

The superheater consists of a long, thick-walled, seamless tube, made of ingot iron, through which the steam makes a single pass from one end of the coil to the other. A cross section of the tube is given (Fig. 377). It is divided into four parts, throughout its length, by walls, the better to transmit the heat taken up to the centre of the current of steam, and to effect a complete super-

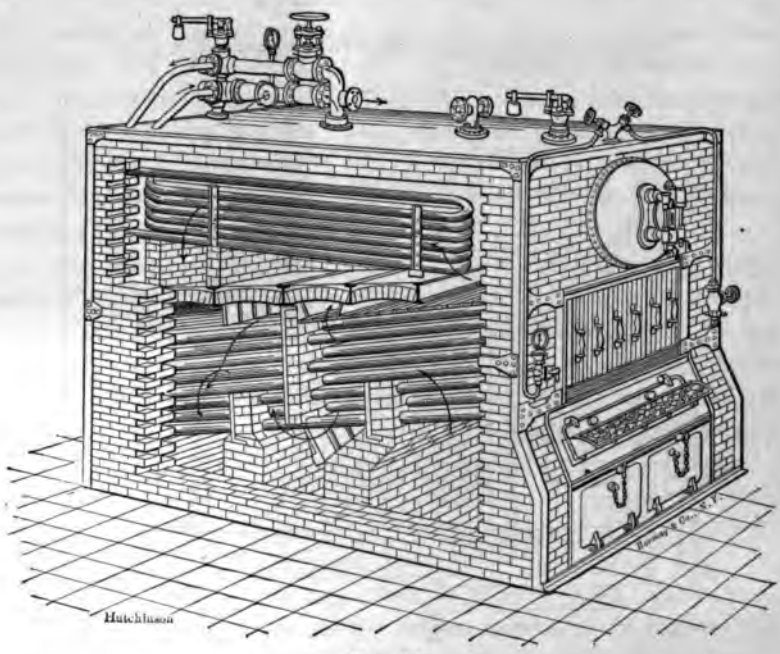


FIG. 376.

heating with a small number of coils, an ample cross-sectional area, and consequent low rate of flow, with little loss of pressure. The tubes have a helical twist in order to give the current a rotating motion, and throw any contained moisture against the hot outer walls, and keep their temperature within safe limits.

The superheater designed by Simonis and Lanz, and illustrated in Fig. 378, is interesting on account of the arrangement of the baffle plates and dampers. The header, into which the wet steam is led, is shown in Fig. 379. It will be seen at once that steam entering the upper left-hand compartment will pass through the U-tubes into the compartment below, then through other tubes

FIG. 377.

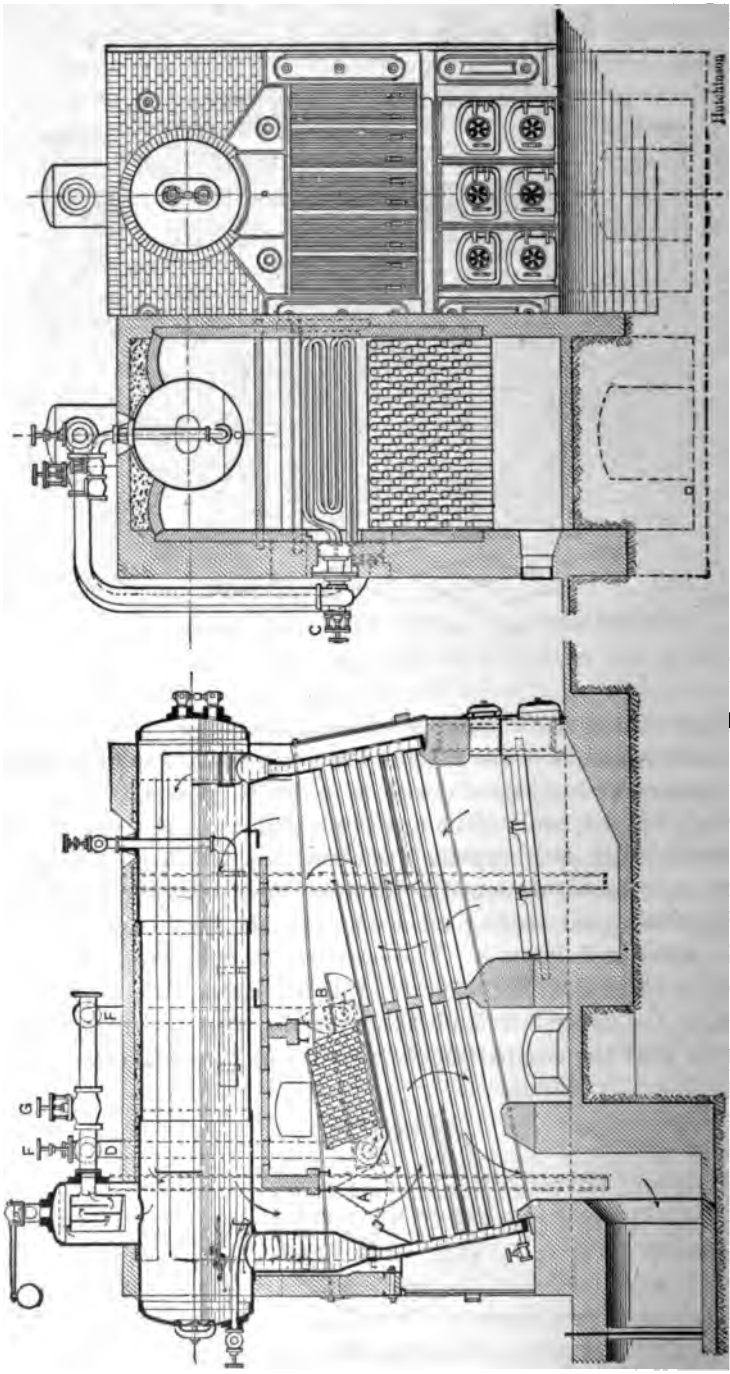


FIG. 878.

into the upper middle space, next to the lower right-hand compartment, and finally to the upper right-hand compartment, and out. The steam generated in the boiler takes a sinuous passage through a separator in the steam drum, and, the valve G being closed, flows through the valve C to the left-hand portion of the lower header, and through the superheating coils in the manner described, becoming thoroughly mixed.

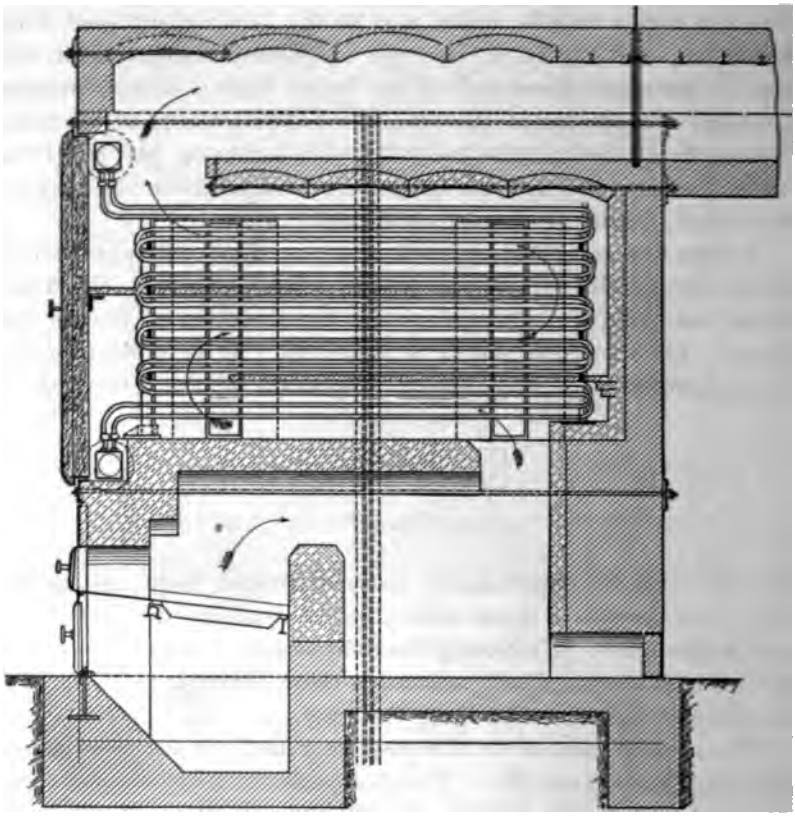
Above the superheating coils is a tile floor extending along under the middle part of the steam drum, and above the water tubes are baffle plates which control the direction of flow of the gases. Dampers are placed at A and B. By manipulating the back dampers at B, any desired proportion of the gases can be

FIG. 379.

sent through the superheating coils, or around them, and in contact with the steam drum above, before reaching the rear end of the water tubes. By closing the dampers at A and B, the superheater can be completely isolated without diminishing the water-heating surface of the boiler in the least.

The arrangement of an independently fired superheater can be seen in Figs. 380 and 381. The steam enters the header at the top, and, dividing into a number of small currents, passes through the coils forward and back ten times, till it collects in, and is discharged from, the lower header. The builders, A. Büttner & Co., use wrought-iron tubes made with very thick walls. Their method of setting a superheater with a water-tube boiler is illustrated in Figs. 382 and 383. It is very similar to the practice of Babcock & Wilcox. An interesting feature of the boiler is the insertion of a trough in the steam drum, connecting with the water legs front and back, to afford an unobstructed path for the water which rises with the steam in the front leg, and thereby to maintain a rapid circulation.

In the Göhrig & Leuchs'sche superheater, Fig. 384, the parallel and countercurrent principle is adopted. Steam is admitted at either end of a series of coils, and is withdrawn at the middle, with the same intent as in the Schmidt system. The arrangement of piping here, as indeed with many types, permits the use of saturated steam, of superheated, or of a mixture of the two.



THE BÜTTNER INDEPENDENTLY FIRED SUPERHEATER.

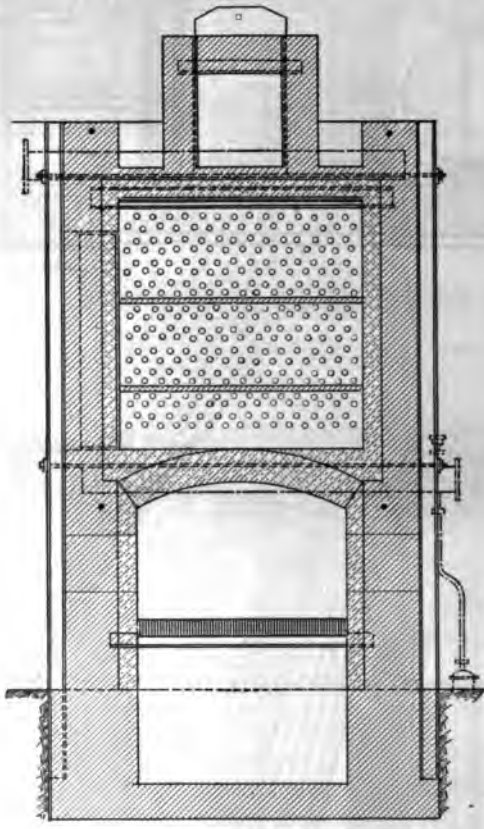
HUTCHINSON

FIG. 380.

The Dürr superheater, as built with a water-tube boiler, is shown in Figs. 385–387. The tubes are so placed that the flow of the gases of combustion is across instead of parallel to them, a detail often thought to be advantageous. Since, with this boiler, field tubes are used, dispensing with a water leg at the back, a superheater can be located as in the Büttner design to good advantage, if it is so desired. The header has five compartments, so that the current of wet steam entering the first is split up in numerous small tubes, reunited and well mixed in the next compartment, split up by another series of tubes, and so on until the last compartment is reached.

Tests were made in February and July, 1898, on marine water-tube boilers of a special design, built by the successors of Dürr &

Co. for the German cruiser "Vineta," and for the Government ship "Sachsen." * In the first case there were 2,285 square feet of heating surface, 2,165 feet of water-heating surface, and 120 feet of superheating surface. The boiler designed for the "Sachsen" which was tested was one of eight. It had about

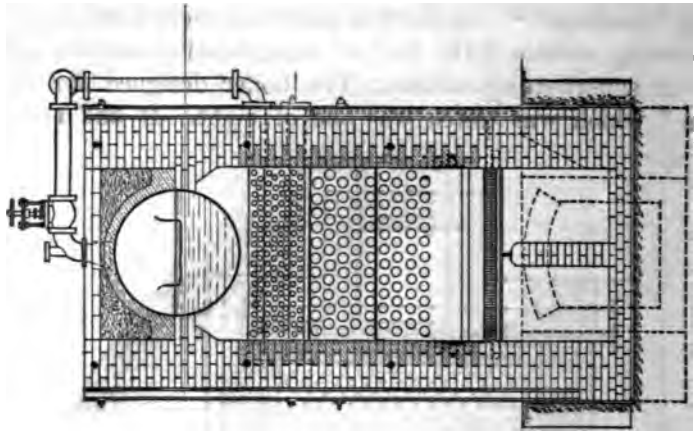


The Büttner Independently Fired Superheater.
HUTCHINSON

FIG. 381.

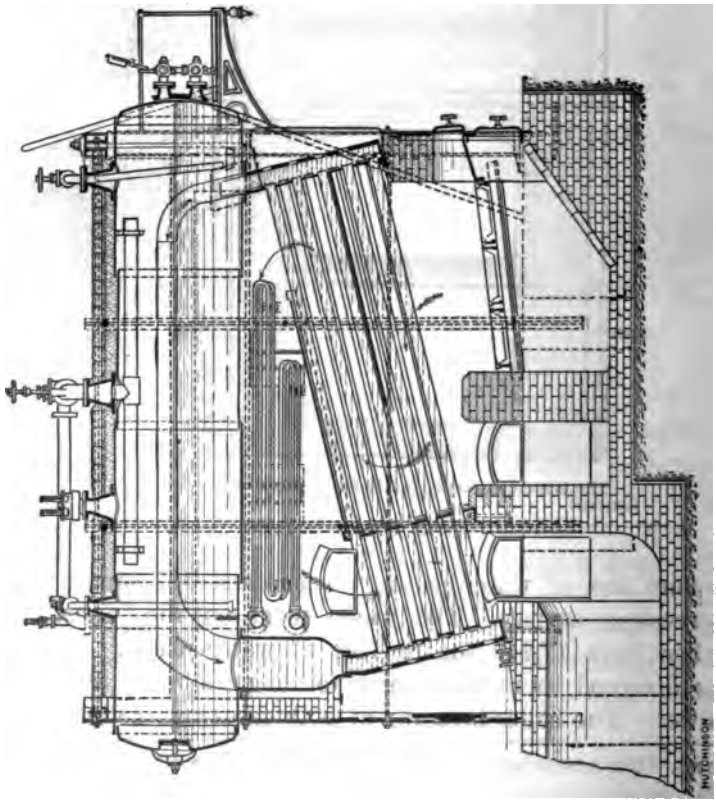
2,155 square feet of water-heating surface and 127 square feet of superheating surface. The whole plant on the "Sachsen" would then have 17,240 square feet of water-heating surface, and was designed to furnish steam for engines rated at 6,000 horse-power. The boiler pressure in both cases was 185 pounds,

* O. Herre, "Die Anwendung des Überhitzten Dampfes im Dampfmaschinenbetriebe."



The Büttner Rapid Circulation Boiler with Superheater. HUTCHINSON

FIG. 382.



THE BÜTTNER RAPID CIRCULATION BOILER WITH SUPERHEATER.

FIG. 383.

and the evaporation per square foot of heating surface per hour, in the first case, nearly 6.5 pounds; in the second, 5.9 pounds. The steam was superheated only 10 degrees, the intention being to make dry steam when driving the boilers hard.

The Göhring superheater recommends itself by reason of the ease with which, in case of necessity, a new element can be substituted for an old one. As the cut, Fig. 388, shows, it consists of

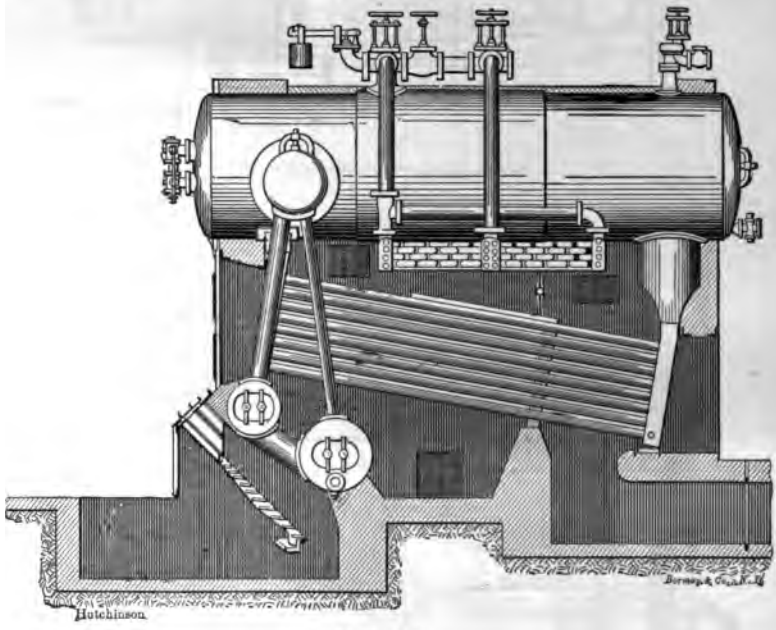


FIG. 384.

a series of spiral coils of wrought-iron pipe. The ends are brought outside of the boiler setting, and connected by means of bolted flanges to headers. Fig. 389 indicates a method of applying it to a double-decked boiler, with provision for isolating it.

Some excellent features are embodied in a superheater patented by R. Hildebrand. It is shown in Fig. 390. Steam from the pipe g enters a separator G, and flows thence to the headers C and D, which connect directly with the superheating coils A and B. A three-way valve, E, controls the distribution of steam to the two coils, and a by-pass, h, permits the water from the separator to flow into the coil A, which is exposed to the hottest gases. In the coil A the steam flows in the same direction as the gases of

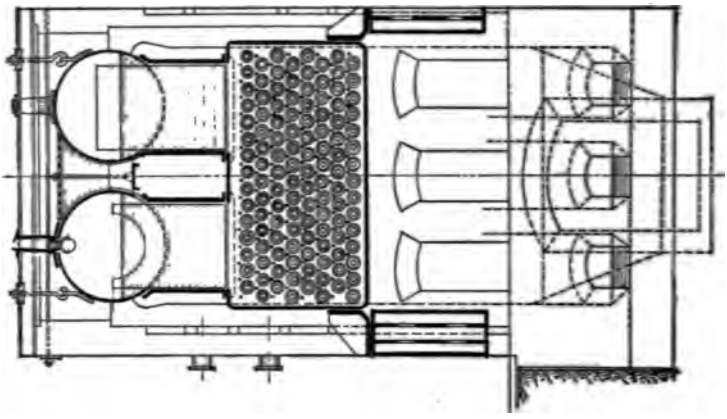
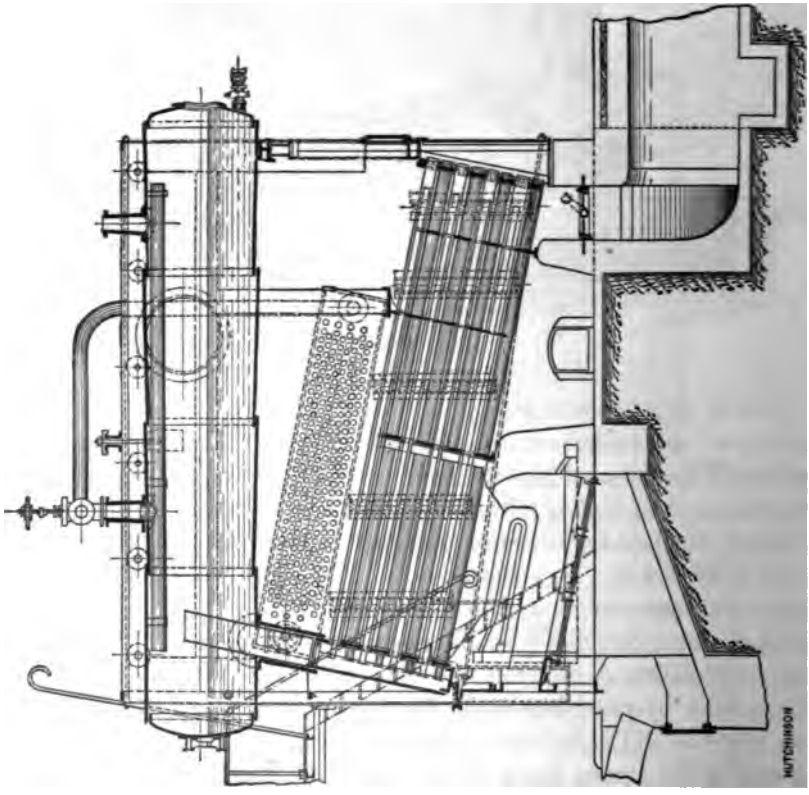
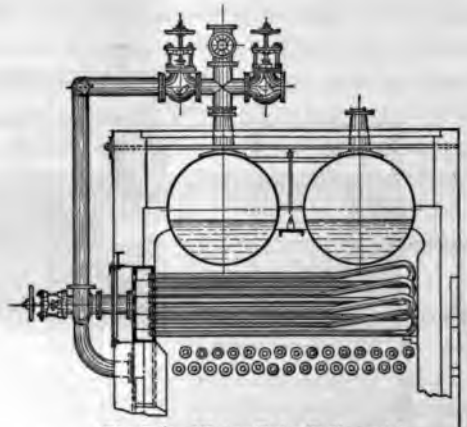


FIG. 396.



THE DÜRR WATER TUBE BOILER WITH SUPERHEATER.

FIG. 395.



The Dürr Water Tube Boiler with Superheater.

HUTCHINSON

FIG. 387.

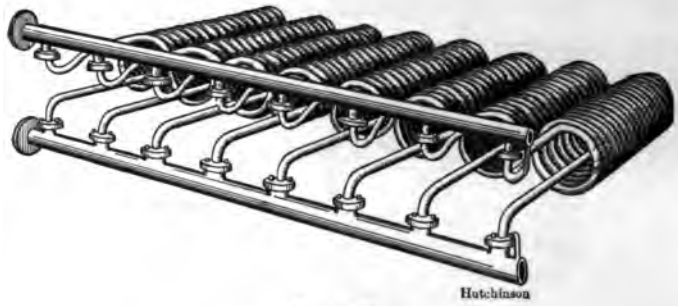


FIG. 388.

combustion, while in the coil B it flows in the opposite direction, the parallel and countercurrent principle of Schmidt being here introduced. The rear coil being exposed to cooler gases, is longer than the front coil. By controlling the distribution at E, an approximately equal temperature in both members should be attained. The superheated steam is withdrawn at H.

In the Fehrmann superheater, shown in Fig. 391, the steam to be superheated is contained in an annular space between a seven-inch and a ten-inch pipe. The larger pipe is worked down to a suitable size at the ends, and a tight joint secured by welding. The hot flue gases pass through the inner tube, and around the outer. Between the tubes are corrugated strips of sheet copper bent into a cylindrical shape, the corrugations being parallel to the axis

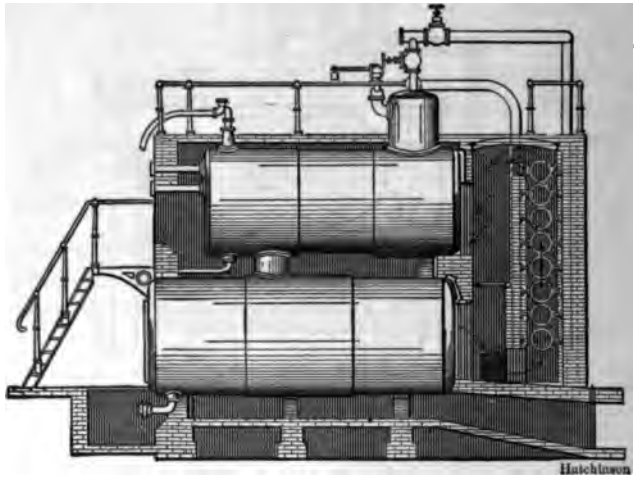


FIG. 389.

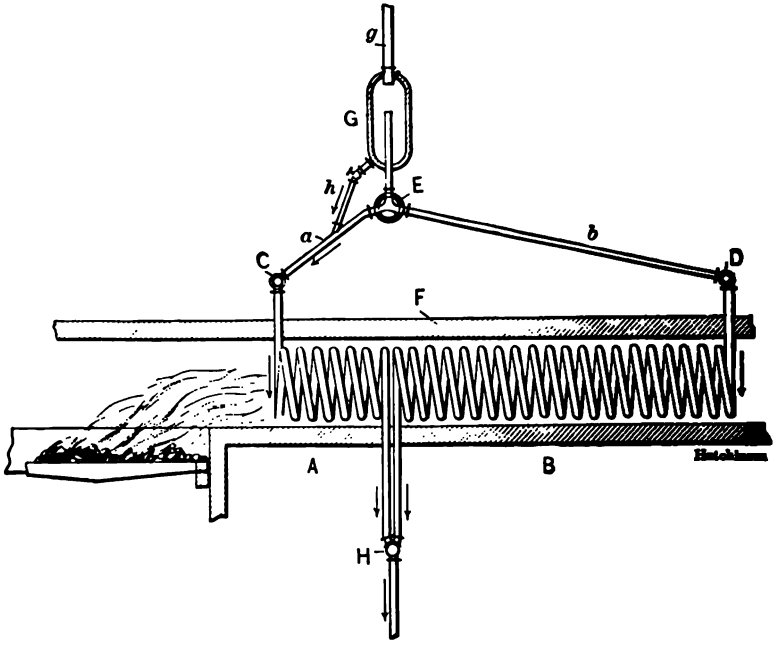


FIG. 390.

of the cylinder, the strips pressing by their own elasticity against both the inner and the outer shell. To secure a better mixture of the steam passing over these plates, they are so arranged that the crests of the corrugations on one plate are in line with the hollows of the adjacent plates. Since copper has six or seven times the heat conductivity of iron, and since there are numerous lines of close contact between the corrugated plates and the inner and the outer tubes, the additional heating surface thus obtained should be very effective.

The cut shows how this apparatus may be applied to an old boiler with little or no interruption to its regular operation. By providing a short cut to the chimney through the superheater, it is possible to control the flow of gas, and the arrangement indi-

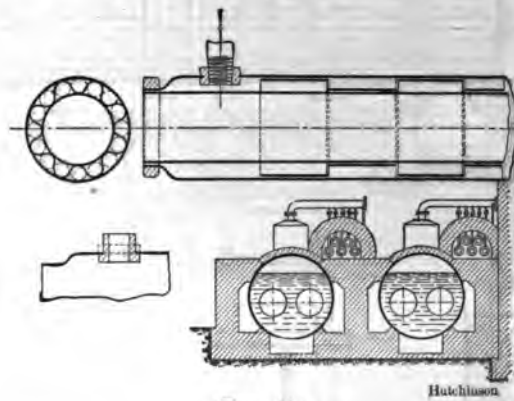


FIG. 391.

cated permits of its being easily thrown out of use whenever it is desirable to do so.

The Schwoerer superheater is shown, in Fig. 392, applied to an internally fired boiler. A glance at the end view shows that it is placed in the side flues where the gases are making their second pass over the water-heating surface. It is made up of ten-foot lengths of cast-iron pipe, ribbed outside circumferentially, and inside longitudinally, to split up the current of steam into small parts, which is important because of its low heat conductivity. The intention is to provide ample heating surface internally and externally, with a compact apparatus, and, by means of the excess metal, to store or give out heat as the flue temperature fluctuates, so as to equalize the steam temperature, which is, in fact, kept fairly constant. A temperature of 750 degrees can

be safely maintained. Dampers are considered unnecessary, and are installed only in exceptional cases.

The joints are flanged, and shaped to let in a ring of special form imbedded in a refractory cement, and then drawn up with bolts. They are said to be absolutely tight under all conditions of temperature and pressure. An independently fired superheater of the Schwoerer type is shown in Fig. 393. The wet steam is admitted at the end nearest the fire, and the superheated steam withdrawn from the far end.

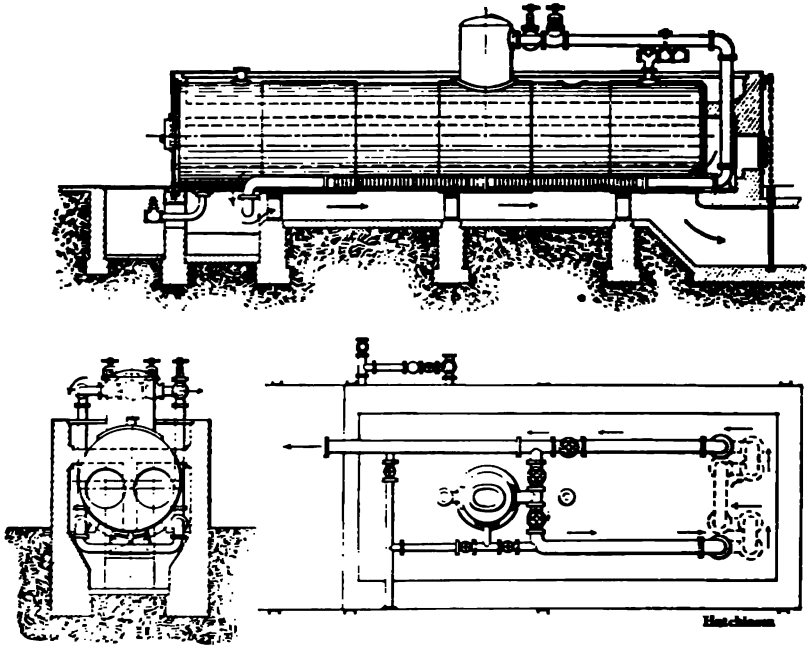


FIG. 392.

Fig. 394 represents a cast-iron superheater built by Gebruder Böhmer of Magdeburg. The elements are ribbed externally, and have a single interior wall extending almost to the far end of the element, which is closed, so that the steam passes along one side and returns through the other, inlet and outlet being at the same end of the casting. Perfectly free expansion, and tight joints, are thus secured with little trouble.

The types illustrated serve to show the variety of ways in which the problem of superheating steam has been attacked. Such

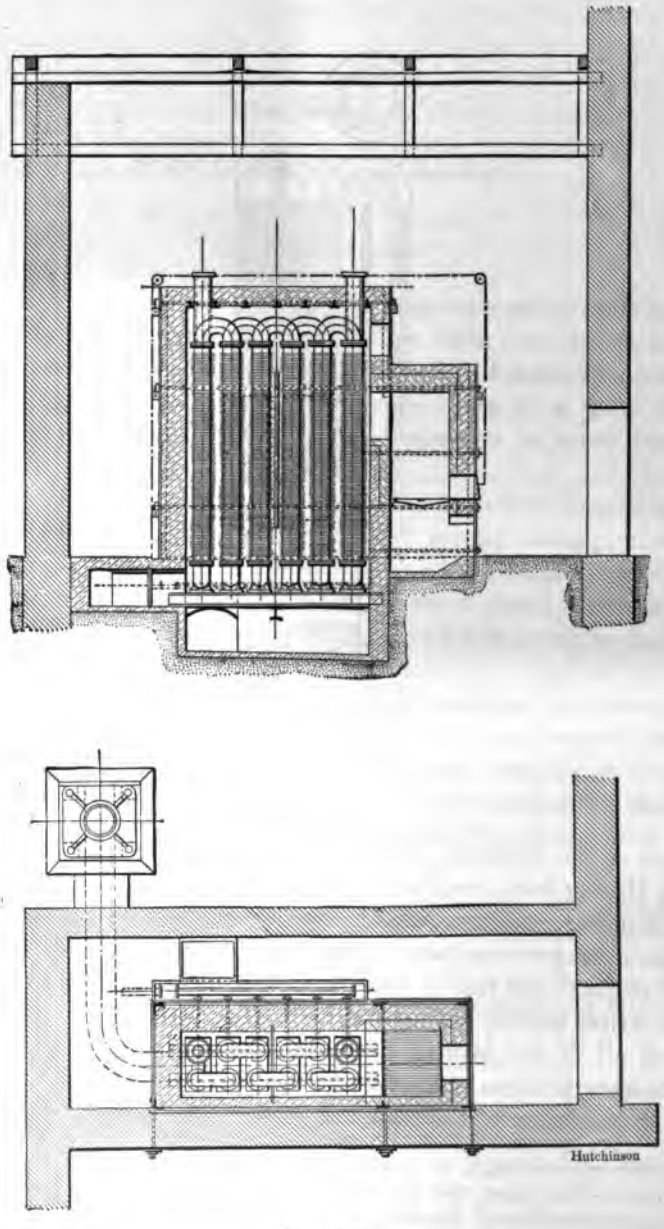


FIG. 393.

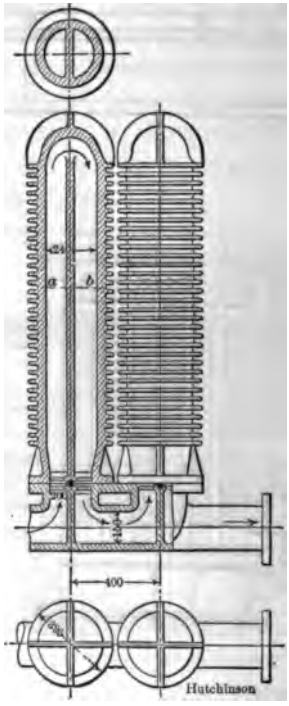


FIG. 394.

types as the Schmidt, the Schwoerer, the Gehre, the Walther, and the Hering have been in the market long enough to demonstrate their utility, and hundreds of installations have been made of each type, over two thousand indeed of the Schwoerer. Others have yet to stand the test of time, and one, the Hildebrand, so far as the writer knows, has not yet been built at all. The fact that almost all of the leading boiler-makers in Germany to-day find it necessary to have some sort of a superheater to offer, is a sufficient indication of the tendency of the times.

NOTE.—This paper was discussed jointly with that of Mr. E. H. Foster on "Superheated Steam," No. 906, p. 939, vol. xxii.

No. 906.*

SUPERHEATED STEAM.†

BY ERNEST H. FOSTER, NEW YORK CITY.
(Member of the Society.)

1. It often occurs that a mechanical improvement attracts more or less wide attention for a time and then falls into disuse, even to the point of being almost forgotten, because of some apparently insurmountable, obstacle to be taken up again at a later date when the conditions governing its use appear to be more favorable.

This seems to be especially true with the subject of superheated steam, by which we mean the practice of raising steam, immediately after its generation in the boiler, to a temperature considerably in excess of the saturation point, without greatly increasing its pressure, for the purpose of working it in a steam engine in this condition.

2. Considerable attention was given to this subject as far back as the year 1850, when we find numerous reports of engine tests which show most remarkable gains, ranging from 30 to 40 per cent., of work done with a given amount of superheated steam over the same weight of steam at a temperature corresponding to its pressure. These early experiments seem to have been practically confined to marine practice, possibly because this was the

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* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† This paper was presented and discussed at the Junior Reunion of Members in New York City, April 2, 1901.

For other discussions on this topic, consult *Transactions* as follows :

No. 572, vol. xv., p. 313 : "Maximum Contemporary Economy of High-pressure Multiple-expansion Steam Engine." R. H. Thurston.

No. 689, vol. xvii., p. 488 : "Superheated Steam." R. H. Thurston.

No. 720, vol. xviii., p. 160 : "Promise and Potency of High-pressure Steam." R. H. Thurston.

No. 853, vol. xxi., p. 788 : "Pumping-engine Test with Superheated Steam." E. H. Foster.

No. 905, vol. xxii., p. 899 : "Practical Application of Superheated Steam." G. A. Hutchinson.

most active field for developing the steam engine at that time, and some idea of the thoroughness of the investigation is obtained from the accounts of long voyages, covering several thousand miles, of which records were kept of the amount of coal burned when the engines were worked with superheated steam and of corresponding voyages using steam without superheating.

3. In his first volume of researches, Chief Engineer Isherwood discussed this matter quite carefully and drew the general conclusion that, while great economy was doubtless to be obtained by using superheated steam in engines, the extra bulk and weight of the apparatus required to produce the superheat, the vulnerability of the same to destruction, but most especially the bad effects of superheated steam on the interior working parts of the cylinders and valves of the engines, chiefly due to the destruction of the lubricating oils before they have had a chance to perform their work, constituted real difficulties which rendered the use of superheated steam at that time undesirable. In spite of this carefully considered condemnation and Isherwood's apparent attempt to dismiss the subject as being the wrong line to pursue in steam-engine development, the question of superheating seems to have continued to attract wide attention. The saving in the coal pile was too great to be ignored, and engine constructors and owners were tempted by the reduction in operating expenses to take the risk of inefficient lubrication and the other attendant difficulties, and so much progress was evidently made that we find in Isherwood's second volume of Experimental Researches, issued only two years later, even more attention devoted to superheating than before and with quite different conclusions. In fact, superheating is distinctly recommended, and the statement made that the average gain in work done of about 33 per cent. may be counted upon. He recommends the steam to be superheated not more than 135 degrees Fahr. and suggests 100 degrees as an average which it is safe to assume because of the inability of the oil to stand a higher temperature without destruction.

The primitive form of the engine, the inefficient insulating covering, and the low pressure used at that time were conditions which undoubtedly lent themselves to making the use of superheated steam exceedingly advantageous, and the difficulties of lubrication, packing of stuffing-boxes, etc., must have been found to be very great in order to cause this practice to be discontinued for so long a time, as it undoubtedly was. At the same time the

compounding of steam cylinders, the introduction of condensers, the improvement in valve gear and general construction, the increase of steam pressures, and other radical improvements were so rapidly brought into general use that the amount of work done per unit of steam was raised to a higher point than ever before, in spite of the drawbacks of moist steam.

4. As the superheater was lost sight of, the improvements which were being adopted in other directions were of such a nature as to diminish its importance. Let us examine these improvements to the steam engine. Have they in any way interfered with it as a user of superheated steam? On the contrary, we find the steam engine of the present day much more suited to the use of superheated steam than formerly. We now have mineral oils which will stand high temperatures without disintegration; we have stuffing-boxes packed with metallic packing; we have cylinders and steam pipes covered with a much more efficient insulating material; we have the wearing surfaces of cylinders and pistons machined to a nicety, and the interior surfaces often highly polished; we have improved forms of balanced and steam-tight valves, and these with our present searching after every device to make the engine more economical, seem to open a field for the superheater to an almost unlimited degree.

In Europe we find much encouragement in this belief. We Americans have characteristically developed the line following the path of least resistance, practically ignoring the question which had seemed to be set aside. Europeans, however, particularly on the continent, also true to their characteristics, seem to have been plodding along in the direction which they knew to be meritorious, gradually working out the problems, and slowly overcoming the obstacles, until we now find them in a state very much in advance of ourselves.

5. In this matter great credit is due to that able Alsatian engineer, G. A. Hirn, and to his successor, Emil Schwoerer, and also to the German engineer, W. Schmidt, for keeping this subject alive. We find them with records of several thousand successful installations of large and small plants, and European engineers educated up to a point where no economical steam plant is seriously contemplated without including the superheater. Most of the records of these tests show a saving in steam and fuel ranging from 6 to over 20 per cent.

6. What is the reason for this increased efficiency of steam when

superheated? Rankine discusses the question in his work on the steam engine.

I. We raise the temperature at which the steam receives its heat and so increase its efficiency without producing a dangerous pressure. According to the law of efficiency of thermo-dynamic engines, the heat transformed into mechanical energy bears the ratio to the whole heat received by the fluid as the range of temperatures is to the absolute temperature at which the heat is received, as follows:

$$E = \frac{T_1 - T_2}{T_1 + 461.2}$$

The more heat supplied per unit of volume of steam to the engine the more work can be obtained from the engine, and the increase of pressure having a practical limit, this extra heat is to be obtained by superheating the steam.

II. The diminished density of the steam employed to do the work lessens the back pressure, or, as commonly expressed, improves the vacuum. This also applies to the air and vapor which are carried with the steam and further expanded by the increased heat, and are consequently contracted to a much less volume when chilled by striking the cooling surface of the condenser; thus the air pump has less work to do.

III. The prevention of condensation during expansion without the use of steam jackets, and in a much more effective manner. This is the most important advantage to be attached to the use of superheated steam. Steam jackets are wasteful aud inefficient when applying heat to the engine. Inefficient because the contact is only with the steam immediately adjacent to the walls of the cylinder, with probably little effect being derived by the steam in contact with the piston and in the interior of the cylinder out of reach of the radiation from the walls; wasteful because of the full effect of heating the exhaust steam after it has done its work in the cylinder during the waning stages of expansion and throughout the exhausting stroke. This is particularly true of engines which have a pause at the end of the stroke, which pause always finds the cylinder full of steam which has completed its work in the cylinder and is ready to be exhausted. Ample evidence of the truth of this statement is found in the high ratio of water condensed in the jackets of direct-acting pumping engines to the amount of steam used in the cylinders.

7. The use of superheated steam is bound to have an important effect on the question of jacketing cylinders. If the superheating is sufficient to carry the steam through the engine to the point of final exhaust without reaching the saturation limit, there is evidently no use for steam jackets. This, however, necessitates the careful covering of the cylinder walls and steam passages to prevent as much radiation as possible, and the logical development of this question would seem to be to abandon the low-pressure jacket first, and follow by giving up the intermediate, and finally the high-pressure jackets, and substitute for these ample intermediate reheaters, between the cylinders, so proportioned that each cylinder would exhaust its steam at a point just sufficiently above the temperature, due to the pressure, to insure the absence of any condensation.

The use of perfectly dry steam and the elimination of condensed water would seem a very practical advantage of superheating. Water is a disturbing element in steam engines and pipes at all times. It increases the friction of the wearing surfaces, interferes with the lubrication, and chokes up the discharge; it produces unequal strains in the metal, due to different temperatures, and often gives leaks at joints which remain perfectly tight under dry steam. Dripping at stuffing-boxes is also avoided in this way.

8. It has always been difficult to determine the actual amount of moisture which is contained in steam; some light is thrown on the subject by the use of superheated steam. For instance, at a working pressure of 125 pounds, 1 per cent. moisture would represent about 20 degrees of superheat. We find under the best conditions of properly proportioned steam pipes, and well covered, a loss of $\frac{1}{5}$ to $\frac{1}{3}$ of a degree Fahr. of superheat per foot of steam pipe. It would not be out of reason to assume that with the ordinary large and indifferently covered steam pipe the loss would reach even as much as 1 degree Fahr. for every foot of pipe; consequently a pipe 100 feet long might lose 100 degrees of superheat, corresponding to 5 per cent. of moisture in the steam, provided the steam was dry on leaving the boiler. Even assuming $\frac{1}{2}$ degree loss per foot, we should have a condensation of $2\frac{1}{2}$ per cent. in a steam pipe of this length.

9. As the friction for superheated steam is much less than for saturated steam in passing, there is not so much loss in ports and passages, and the size of the pipes may be considerably reduced. The tendency in this country has been to use steam pipes which

are much too large. Good practice with superheated steam recommends that the velocity should not be less than 100 feet per second passing from the boiler to the engine. Of course, this means ample steam receivers in proximity to the engine, and a very good plan would be to have these receivers fitted with reheating tubes containing steam which is being circulated through the superheater, or else a portion of the hot furnace gases, diverted from their course for this purpose, and returning again to the boiler flue by means of an induced draft.

Having once evaporated water into steam at an expense of 1,000 or 1,100 heat units, why allow it to condense and drop over 800 of the heat units before doing its work, and rush forward more steam to take the place of that which is lost, instead of supplying the necessary heat for the reëvaporation, thus saving the heat originally expended?

10. As to the present effect of superheated steam on lubricating oils and stuffing-box packings, it may be said that the present practice provides, and in fact already demands, oil and packing which will easily withstand these conditions. Mineral oils have supplanted the old vegetable oils and animal fats which were formerly used with machinery, and metallic steam packings have been universally adopted. Both of these were necessitated by the temperatures due to the steam pressures in the vicinity of 150 pounds to the square inch, which is now common practice; hence, we already have the way thoroughly paved for the introduction of superheated steam.

11. We have mentioned European practice in this direction. There we find no prominent central station designed without providing for superheated steam; engine builders make guarantees contingent upon it, giving an advantage averaging about 12 per cent. in pounds of steam per horse-power based upon the steam being superheated. The range of temperatures has resolved itself into recommending the use of steam at between 500 and 600 degrees Fahr. Good practice abroad may be said to lie in the vicinity of 570 degrees. Experimenters have observed that steam expands more rapidly during the first 20 degrees of superheating than when further raised in temperature; consequently, the first effects are proportionately more beneficial.

12. The method of constructing the superheater naturally presents the most important aspect of the situation after deciding that the results are beneficial and desirable.

Dismissing the subject of superheating by means of wire-drawing as being inefficient and impracticable, the methods resolve themselves into a system of tubes or pipes, through which the steam is passed after leaving the boiler on its way to the engine; these pipes being subjected to the hot furnace gases, either in connection with the steam boiler itself or in a separate setting having a fire of its own. In large plants it is usual and even more desirable to set the superheater by itself; and it is placed alongside of the boiler as a continuation of the battery, with fronts and setting similar to the boilers, and fired in the regular manner as the boilers. The fact that the results are found to justify such an addition to the plant is the best testimony in favor of superheating.

Much rivalry exists between the use of cast-iron and wrought-iron tubes for superheaters, and there seem to be well-defined governing conditions in different instances where either one or the other is found the more desirable. For general use, however, the author unquestionably leans toward the cast-iron construction, believing that it possesses greater durability, and, because of the greater mass of heated metal which serves to maintain the temperature of the steam at a more even point, not being so much affected by the working of the fire. For example, when the fire door is open the blast of cold air taken in has a chilling effect on the superheater, and is much more pronounced if the tubes are of light wrought-iron construction than if they are constructed of cast iron with a correspondingly greater thickness.

The same objections which are raised to the use of cast iron in boiler construction cannot apply to superheaters. The presence of water in a boiler gives rise to unequal temperatures, which produce severe internal strains in the metal, whereas a superheater contains no water, and the comparatively even temperature of the steam relieves the metal of all strains except those due to the bursting pressure.

The cast-iron superheaters which the author inspected had great strength and durability; some of them had been in use for six years without giving the slightest trouble or showing signs of deterioration.

13. The point of application of this type to the boiler varies with the construction of the latter. For instance, the most favorable location on a Babcock & Wilcox boiler is immediately over the tubes and under the shell; the same is also true of a Heine boiler;

but at the same time a good arrangement may be made in either of these types by placing the superheater back of the bridge wall and underneath the tubes. In the independently fired boiler of the marine type the superheater may be placed in the main flue or at the back of the boiler where the gases are turned up to enter the tubes. In an ordinary return-tubular boiler the flue at the back, immediately at the entrance to the tubes, is a very appropriate place for the superheater, as on account of the high temperature at that point the heating surface may be distributed with great efficiency.

The wrought-iron construction for superheaters undoubtedly has its useful field. The lightness and compactness of this form of apparatus are greatly in its favor. With well assured circulation, a comparatively low temperature of hot gases, and especially where a moderate degree of superheating is required, good results should be obtained.

The Babcock & Wilcox Company make a simple and ingeniously arranged superheater of this type consisting of two cast-iron headers set parallel and adjacent to each other, with openings facing in the same direction. The headers are joined by rows of $1\frac{1}{4}$ inch wrought return bends, which extend out into the hot gases.

This arrangement is well adapted to the popular form of the Babcock & Wilcox boiler and efficiently utilizes the triangular space between the horizontal drum and the tubes.

14. Aside from its application to steam plants where the engine is in close proximity to the boiler, the superheater has an immense field as a relay agent. In large plants where steam is conducted from one central boiler plant to other buildings, often at a considerable distance, a superheater with a comparatively small gas, oil, or coke fire may be placed at the far end of the pipe and add enough heat to the steam not only to evaporate all the moisture produced by loss of heat in transit, but to raise the temperature to such a degree of superheat as to increase its efficiency in the engines as before mentioned.

15. A large plant of this sort was inspected by the author in a steel works and rolling mill at Rothe Erde, Germany. In this case there were fifty Cornish boilers, aggregating 54,000 square feet of heating surface. Superheaters are fitted to each boiler in the side flues, while three independently fired superheaters are placed at the termination of a steam pipe 1,000 feet long leading from a battery of twenty-four Cornish boilers.

Oil is burned in these works as fuel, and the officers of the company stated that the superheaters had been in use since 1896, without giving the slightest trouble, and that repeated tests had shown a saving in fuel at the former plant of from 17 to 20 per cent., while in spite of the long steam pipe and numerous branches the latter installation shows an increase in economy of from 10 to 13 per cent.

In this plant and many others, all types of slide valve and Corliss and poppet-valve engines were found working with superheated steam, and we were unable to secure any testimony of a derogatory nature to the practice, or which would suggest the necessity of providing any special means for lubricating under such conditions.

16. As to the actual results which may be promised to any prospective user of superheated steam, we shall content ourselves with the statement that this depends entirely upon the surrounding conditions. That some benefit may be derived is without question. It is a remarkable fact that throughout all the mass of evidence which has been accumulated during many years, one result seems to be universal, however vague or incomplete the recorded data—superheating always results in a considerable economy of steam used.

After all, a conclusion of this sort is about all which could be expected from a mass of reports, from widely different sources, of tests made according to no common standard. In such cases the data are bound to be incomplete, but not altogether without value on this account. If we find such important items as the temperature of the fire, rate of combustion, temperature of escaping gases, efficiency of boiler, amount of draft, etc., omitted, these tests may be regarded of less value from a scientific point of view, or as an aid to the constructor; yet we are glad to have them for the assistance which they give us in forming an opinion of the general subject.

17. We feel convinced that much improvement in steam-engine economy may be obtained by using superheated steam, even in the highest class of engines of the present day.

We believe the superheating of steam will give the triple-expansion engine somewhat of a setback. We have records of tests under which a compound engine with superheated steam has given better results, under similar conditions of work, than a triple expansion.

The arguments bearing on this case would be too lengthy to mention here, but it will be readily admitted that with the use of superheated steam some of the reasons for the multiplication of steam cylinders disappear.

We expect to see an indicated horse-power easily developed with 10 pounds of steam per hour in a compound engine, and already have records of 10.12 pounds for an indicated horse-power per hour on an 800 horse-power compound Corliss engine in Europe.

The effect in fuel saved is not necessarily in the same proportion to that of steam saved by employing superheaters. Many tests show a larger proportion of fuel saved than of steam, while in others these relations are reversed.

The superheater virtually adds to the heating surface of the boiler. It may truthfully be claimed to utilize this surface more efficiently. In a well proportioned plant where the waste gases are rejected at a low temperature, the net gain by superheating will obviously be less than in a plant where available heat is allowed to find its way to the chimney. We are always sure of some improvement, but each case must be considered by itself in determining the amount.

The author was able to gather much information on this subject while in Europe, and has collected many reports of tests. He has had opportunities of making only two such tests personally. The results of one of these were given to this Society at a recent meeting.*

DISCUSSION.

Mr. F. A. Scheffler.—Mr. Foster's remark in paragraph 12, which refers to the subject of superheating steam by wire-drawing, requires modification to the extent that he is perfectly justified in making this statement in so far as it may refer to *only* superheating the steam to a high degree of superheat, but I wish to qualify the statement to this effect—that the slight amount of wire-drawing (less than 1 per cent.) which occurs in the "Potter" Mesh Separators (a device located in the steam space of any kind of a boiler to take the moisture out of the steam) is *not* "*inefficient* and *impracticable*." This small amount of wire-drawing increases the temperature of the steam passing through the "Potter" Separator by a slight amount of superheat, and

* "Pumping-engine Test with Superheated Steam." E. H. Foster, vol. xxi., p. 788, No. 853.

at the same time decreases the amount of moisture in the steam by from *fifty* to *sixty* per cent. This statement can be substantiated; and as the "Potter" Mesh Separator is being specified by some of the best engineers and architects in this country, no further comments are necessary, except perhaps to call attention to the fact that the device, from my personal knowledge, reduces to a very considerable extent the trouble referred to by Mr. Foster in paragraph 7 that—"Water is a disturbing element in steam engines and pipes at all times. It increases the friction of the wearing surfaces, interferes with the lubrication, and chokes up the discharge; it produces unequal strains in the metal, due to different temperature, and often gives leaks at joints which remain perfectly tight under dry steam. Dripping at stuffing-boxes is also avoided in this way."

Prof. W. F. M. Goss.—The use of superheated steam in locomotive service appears to have given results similar to those obtained by the use of superheated steam in other classes of steam-engine service. The German locomotive to which reference has been made is a simple engine fitted with a very efficient superheater. It is my understanding that this engine gives substantially the same steam efficiency as the better class of German two-cylinder compounds. I understand, also, that the experience with this particular engine has not yet advanced to a point where they have ceased to have trouble in keeping their superheaters tight.

The general subject which is presented by the papers is of very great interest, and the papers themselves present an excellent summary of the facts involved. It does not seem to me, however, that a disclosure of these facts constitutes a startling revelation. I do not think that the American engineer has been caught napping. He has for many years appreciated the very great advantage which is to be derived from the use of superheated steam, but he has not been blind to the difficulties to be encountered when it is attempted to make these advantages available in the routine of every-day service. He has generally preferred to improve engine efficiency by the use of multi-cylinders rather than by the adoption of superheated steam with a fewer number of cylinders. In doing this he has followed lines of least resistance. He has gotten his results, and has had few difficulties with which to contend. The subject is a live one, and will continue to be so. As matters now stand, I do not believe that

there are many engine plants in Germany or elsewhere using highly heated superheated steam which are making money for their owners because they use superheated steam.

Mr. Storm Bull.—I am very much interested in this subject and have been for years. I suppose it is true, as the last speaker has said, that American engineers have not been unaware of the fact that by the use of superheated steam, if it could be practically used, better economy might be obtained. The fact is, nevertheless, that practically no work has as yet been done along that line in this country. Consequently, I think we had better admit frankly that we have, as the paper states, neglected the subject. We have neglected it, and I think it is high time that we take it up. The increase in economy which we have obtained in our engines by other means—by compounding, jacketing, and so on, has been very great; but in addition to that we can get still higher economy by the use of superheated steam, as has been shown conclusively by a number of experiments and tests in Europe. Therefore, it is not the choice, I should say, between compounding and superheated steam. It is simply a question of adding, by the use of superheated steam, still further to the economy already obtained by compounding. The practical question of the durability of the superheaters must, of course, be carefully considered, but from the experience gained in Europe, it seems that all such difficulties have now been fairly overcome, as well as the difficulties of lubrication which, in former years, made the use of superheated steam almost impossible. As soon as American engineers in general realize that such good results can be obtained by the use of superheated steam, I am fully convinced that it will be very generally used.

Mr. C. G. T. King.—In the Commonwealth Electric Plant, at Fifty-sixth and Wallace streets, at the South End of Chicago, there are four boilers of 400 horse-power units, equipped with superheaters. The occasion has not yet arisen in which they can be tested. Two more boilers of the Babcock & Wilcox type are at present being installed, and they are going to be very thoroughly tested this summer. Two engines of 1,000 and 400 kilowatts have been installed in that plant, and are now running, and at present another is being installed; when that third engine is completed very exhaustive tests are going to be made of all of them, with and without superheated steam in all its phases.

The Southwark Foundry and Machine Company, in Philadelphia, are experimenting now with it. They have four boilers, and the battery and the superheater are built separate from the battery of boilers and heated by a slow coal fire, using only about ten shovelfuls of coal in a day's run. They have been able to shut down one of their boilers; but they are not ready yet to give information to the public, though they expect to be shortly.

Mr. George N. Comly.—Following the line of thought just expressed, I might state that I know of a mill near Wilmington, Del., where they desired to carry their steam a long distance from the boilers, and, of course, there is naturally more or less condensation through the length of pipe, although it is well insulated. They introduced at a convenient place on the pipe a superheater, which was practically about the same as a vertical boiler, but having only a very small amount of fire in it, and succeeded in drying the steam and slightly superheating it with very gratifying results. The steam was then passed on to the place where they desired to use it. They claim that the small amount of fire, drying and superheating the steam, produces very good results.

I do not know whether or not any definite tests were made of the relative efficiency with and without the superheater, everything considered; but it was used at mills where they go into such things very minutely, and usually make their own tests.

In regard to this question of superheated steam, I remember that on one occasion some one wanted them to try a steam superheater over the bridge wall, introducing steam over the fire. The mill-owner made his own tests, and I think in that particular instance the plan did not prove to be much of a success. Whether the failure was due to the peculiar conditions existing in his plant or not, I do not know; but, in other cases, I believe it has been quite highly recommended.

Prof. Charles L. Weil.—I would like to ask the last speaker whether I understood him correctly as saying that the superheating was done at that point in the line where the steam was used?

Mr. Comly.—Yes, sir. They had a large battery of boilers, and a great deal of steam was used close to the boilers; but in the instance where the steam was superheated, it was done after the steam had travelled, I should say, about 600 feet from the

boilers. A superheater was installed and gave very good results, not superheating all the steam produced by the plant, but simply that which was carried to this isolated place. I had nothing to do with the arrangement, and am simply giving hearsay information about it. I understand it was on certain apparatus where it was particularly desirable that they should have especially dry steam—more particularly so than with the majority of their work; and, in order to get it, especially at this distance from the boiler, they simply introduced a small vertical boiler and heated the steam, producing the desired effect.

Mr. William A. Bole.—I think it can safely be stated that superheated steam is a strictly perishable article, and will not keep well while being transported long distances; therefore there would seem to be some wisdom in a system which will superheat the steam immediately before it enters the engine in which it is to be employed. Even when the pipes are covered with the best of non-conductors, it is difficult to maintain a superheat obtained near the boilers when the steam must be conveyed to engines at any distance.

I think that the more general introduction of superheated steam is almost wholly a matter of proper apparatus, and, as in other cases, this particular feature of engineering will obtain a stimulus by some manufacturer actually putting upon the market a practical and easily operated appliance for the purpose.

Something like a dozen years ago I personally made some experiments on superheated steam at the works of the Westinghouse Machine Company, in Pittsburg, which did not amount to much, except for personal interest and the few isolated facts which were developed. In this apparatus I used natural gas as a superheating agent by running a line of gas pipe underneath the steam-supply pipe, and burning the gas in the manner of foot-lights whose flame impinged upon the steam pipe. This application was made as close as possible to the engine, and I succeeded in superheating the steam to an extent of possibly 100 degrees Fahr. above the normal. The effect upon the steam consumption of the engine was very marked, particularly in the case of light loads. The engine employed was of about 50 horse-power, and the most noticeable reduction in steam consumption was shown to be as much as 15 per cent., due to the use of superheated steam, the gain falling off in terms of percentage as the

load became heavier, due to the insufficiency of the apparatus for larger horse-powers.

The use of superheated steam involves certain difficulties which must not be overlooked, for in these tests we succeeded in burning out gaskets, and even destroyed some of the valves having soft metal seats, these valves being located in the steam line between the superheater and the engine. One of the difficulties which may be experienced in such an application would be that of regulating the quantity of heat applied to meet the varying condition of loads in the engine itself—fluctuations from heavy loads to light and the reverse are frequent and severe; and a device intended to superheat steam for such service would have to be very flexible in its application, and capable of rapid modifications to suit such a condition.

Certain features of engine design will doubtless become compulsory, and the use of sliding valves or rolling valves, such as the Corliss type, may have to be discarded, owing to the difficulty of lubricating them for steam with a high degree of superheat.

In the turbine engine it is expected that superheated steam will be of very great advantage, and in this type of construction the objections incident to lubrication of valves and other parts will be eliminated. There should be much less objection to employing superheated steam in the turbine than in the case of the reciprocating engine.

Mr. King.—I would like to make an addition to Mr. Foster's paper in paragraph 13, where he says that the Babcock & Wilcox Company make a simple and ingeniously arranged superheater of this type, consisting of two cast-iron headers set parallel and adjacent to each other, with openings facing in the same direction. The addition I would make is this, that now they are making those headers of steel instead of cast iron.

*Mr. Ernest H. Foster.**—In connection with the remarks of Mr. Weil, it is undoubtedly beneficial to superheat at the boilers before entering a long steam line, because condensation is thereby diminished as well as leakage at the joints of the pipe and friction in passing through it. Prof. Storm Bull speaks of superheaters as being short-lived. The author believes that superheaters are now made with satisfactory lasting qualities.

* Author's closure, under the Rules.

There is one point in connection with superheating which I failed to mention in the paper, and that is in connection with steam turbines. The Society may be familiar with some of the steps which have been taken in this direction recently. Of course, it has not been general, but there have been one or two notable examples of steam turbines constructed for a large power, and so far the indications seem to be that a very large saving in fuel is to be obtained by using superheated steam in steam turbines. It may be that this will prove a better field for the use of superheated steam than the ordinary steam engine, granting that this is also a very good field. I am in hopes that before the next meeting of the Society there will have been some very conclusive experiments made on a large scale in this direction, and, if possible, I shall try to get the figures for the benefit of members.

No. 907.*

DETERMINATION OF FLYWHEELS TO KEEP THE ANGULAR VARIATION OF AN ENGINE WITHIN A FIXED LIMIT.

BY J. I. ASTROM, HELSINGFORS, FINLAND.
(Junior Member of the Society.)

THE purpose of a flywheel, attached to an engine, is to maintain a certain degree of isochronism of rotation. The disturbing elements are the engine impulses and variations of load. Absolute uniformity of rotative speed, however desirable it may be in many cases, can never be obtained. Considering one single revolution, the engines of the turbine type, working under a steady load, come very close to perfection in this respect, but it is, on the other hand, well known that these engines leave much to be desired in regard to regulation during a longer run and with a fluctuating load. Here the ordinary steam engine only, with reciprocating parts, will be treated, where a certain angular variation always must exist. But the amount of variation can, by means of a flywheel possessing a sufficient amount of inertia, be reduced to almost any desired degree.

It is necessary in many cases, not only that the number of revolutions per unit of time should be as constant as possible, under varying conditions of load, but also that the variation of speed during any one single revolution of the engine should not exceed a certain narrow limit, depending upon the requirements of each case. And it may also be needed to know the effect of the speed variation allowed, or the angular variation resulting therefrom, from which, further, the displacement of a point in connection with a revolving part of the engine can be determined. As a point of this kind the centre of crank pin may be conveniently chosen. In the following, all acting forces will be reduced to this point, the acceleration, speed, and displacement of which will be considered as representing the condition

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

of the engine, and an attempt will be made to indicate a method by which the regulating capacity of a flywheel upon the motion of an engine may be positively determined. Some attention also will be given to the influence of choosing other crank angles for compound engines than those found in general practice.

The period here to be investigated will be limited to one revolution, but it may, if the variation of load and the regulating action of the engine are known, be extended to a number of successive revolutions.

Let the first proposition be to determine, for a single-cylinder, double-acting condensing engine, developing a given number of horse-powers at a certain speed, a flywheel, such that the displacement of crank pin during one revolution becomes limited to a fixed quantity. The principal thing needed is, as in all flywheel calculations, a curve, representing the variable force exerted on the crank pin during that period in the direction of its motion, or the rotative effect of the engine.

The following are the factors with influence upon the rotative effect:

A—The effective steam pressure upon the piston.

B—The inertia of the reciprocating masses.

C—The weight of the reciprocating parts (in horizontal engines of the connecting rod only).

D—The weight of crank pin and unbalanced part of crank.

E—The throw of the connecting rod.

A.—The rotative effect of the steam pressure.

Let the following be the notation of Fig. 395:

s = space covered by the piston at a certain instance figured from that end of the stroke from which it moves.

ω = the crank angle corresponding to s, figured from 0 to 180 degrees, starting from each dead centre position.

R = the crank radius.

L = the length of connecting rod.

The position of the piston is then given by the equation—

$$s = R\left(1 - \cos\omega \pm \frac{1}{2}\frac{R}{L}\sin^2\omega\right) \quad . \quad . \quad . \quad . \quad (1)$$

The upper sign (+) is for points of the stroke towards the shaft, or the forward stroke; the lower sign (−) for points of the

backward stroke. This formula is approximated, but the error is very small.

The circumference of the crank-pin circle is divided into a number of equal parts. Twenty parts have been found to be

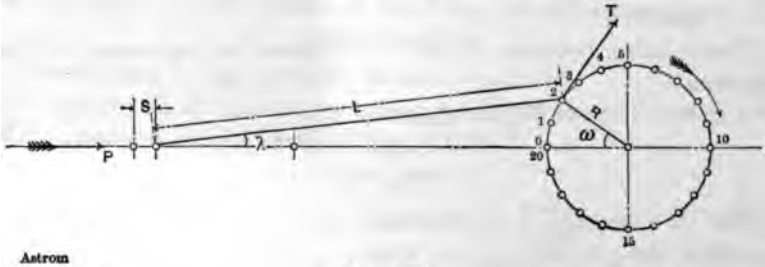


FIG. 395.

sufficiently many, giving accurate results without rendering the subsequent operations too cumbersome. This division corresponds to points on the crank-pin circle 18 degrees apart. For

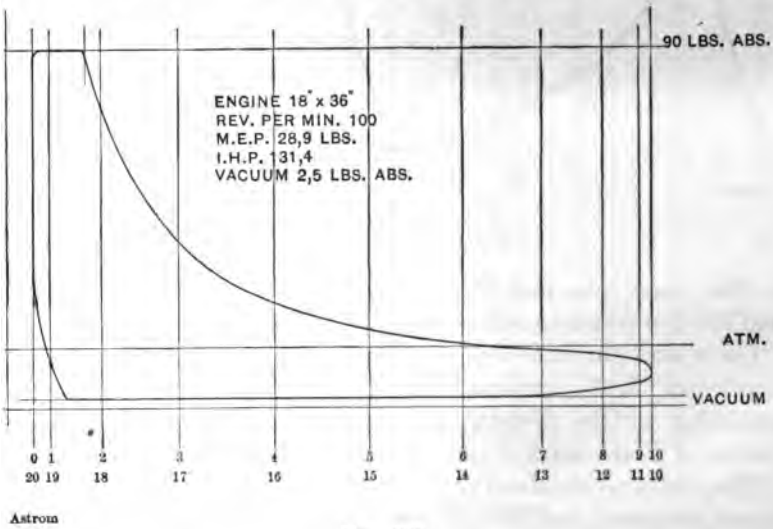

90 LBS. ABS.
ENGINE 18" x 36"
REV. PER MIN. 100
M.E.P. 28,9 LBS.
I.H.P. 131,4
VACUUM 2,5 LBS. ABS.
ATM.
VACUUM
0 1 2 3 4 5 6 7 8 9 10
20 19 18 17 16 15 14 13 12 11 10
Astrom

FIG. 396.

the sake of convenience the points may be called by numbers from 0 to 20. On the steam card of the engine (actual or theoretical) ordinates are drawn indicating the positions of the piston corresponding to these points (Fig. 396).

The total effective steam pressure P on the piston is calculated in each point. Let, further (see Fig. 395),

λ = the angle enclosed between the centre lines of the engine and the connecting rod;

T = the effort on the crank pin in the direction of its motion, due to P.

The relation between P and T will then be expressed by the equation—

$$T = \frac{\sin(\omega \pm \lambda)}{\cos \lambda} \times P \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The double sign is to be read as in equation (1). By this equation the pressure on the piston in each point is transferred

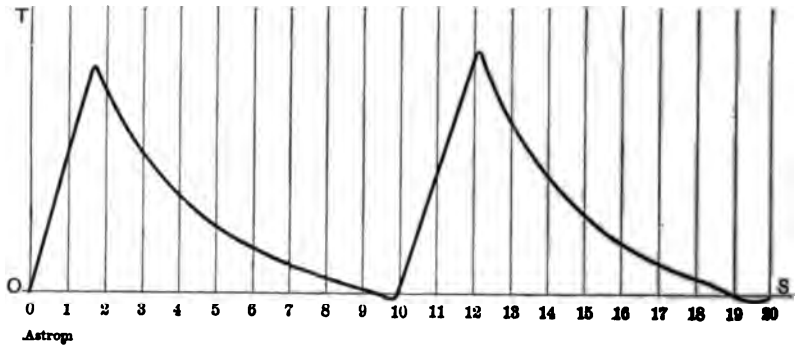


Fig. 397.

to the crank pin, and Table I. gives the values of T for $P=1$ and for five common ratios between L and R.

On a straight line OS (Fig. 397), representing the rectified crank-pin circle, ordinates are raised through points, corresponding to the division made, and on these ordinates the values of T are marked off.

The curve so obtained represents the rotative effect due to the steam pressure, and the area enclosed by OS, the ordinates at O and S and the curve the work done. Therefore, the accuracy of the proceeding and of the curve can be checked by getting the mean effort T_m, which must satisfy the equation—

$$T_m = \frac{33000}{2 \pi R} \times \frac{N}{n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where

N = number of indicated horse-powers developed by the engine, and

n = number of revolutions per minute.

B.—Influence of the inertia of the reciprocating masses upon the rotative effect.

In addition to the notation already used, let

G = weight of all the reciprocating parts (piston and piston rod, crosshead and (connecting rod*));

u = the variable velocity of the piston;

v = the mean velocity of the crank pin $= \frac{\pi R n}{30}$;

t = the time needed by the piston to cover the space s, figured from the moment the crank pin passed the previous dead-point, and

a = the acceleration of the piston at the time t.

Equation (1) gave

$$s = R\left(1 - \cos\omega \pm \frac{1}{2}\frac{R}{L}\sin^2\omega\right),$$

from which by differentiation

$$u = \frac{ds}{dt} = R\left(\sin\omega \pm \frac{1}{2}\frac{R}{L}\sin 2\omega\right)\frac{d\omega}{dt}.$$

But, $$Rd\omega = vdt, \text{ or } \frac{d\omega}{dt} = \frac{v}{R},$$

and consequently, $$u = v\left(\sin\omega \pm \frac{1}{2}\frac{R}{L}\sin 2\omega\right) \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Since, further, $$a = \frac{du}{dt},$$

the acceleration of the piston becomes

$$a = v\left(\cos\omega \pm \frac{R}{L}\cos 2\omega\right)\frac{d\omega}{dt},$$

and by substituting the value of $\frac{d\omega}{dt}$, as above,

$$a = \frac{v^2}{R}\left(\cos\omega \pm \frac{R}{L}\cos 2\omega\right). \quad . \quad . \quad . \quad . \quad . \quad (5)$$

If

P_a = the force required to give to the reciprocating masses the acceleration a, and

* Compare Section E, page 966.

g = the acceleration due to the force of gravity, then

$$P_a = \frac{G}{g}\frac{v^2}{R}(\cos\omega \pm \frac{R}{L}\cos 2\omega). \quad . \quad . \quad . \quad . \quad (6)$$

TABLE I.

Position of Crank.	Values of T.					Position of Crank.
	$L=4R$	$L=4\frac{1}{2}R$	$L=5R$	$L=5\frac{1}{2}R$	$L=6R$	
0	0.00000	0.00000	0.00000	0.00000	0.00000	20
1	0.38278	0.37592	0.36894	0.36331	0.35865	19
2	0.70799	0.69437	0.68355	0.67480	0.66789	18
3	0.93037	0.91646	0.90602	0.89642	0.88895	17
4	1.02667	1.01782	1.01088	1.00531	1.00086	16
5	1.00000	1.00000	1.00000	1.00000	1.00000	15
6	0.87535	0.88430	0.89124	0.89681	0.89945	14
7	0.68767	0.70158	0.71202	0.72161	0.72901	13
8	0.46769	0.48123	0.49245	0.50080	0.50815	12
9	0.23526	0.24212	0.24910	0.25469	0.25939	11
10	0.00000	0.00000	0.00000	0.00000	0.00000	10

Here it is again convenient to have the values of the quantity inside the bracket tabulated, and Table II. below gives these values for the five ratios of R to L used before.

TABLE II.

Position of Crank.	$\cos\omega \pm \frac{R}{L}\cos 2\omega$					Position of Crank.
	$L=4R$	$L=4\frac{1}{2}R$	$L=5R$	$L=5\frac{1}{2}R$	$L=6R$	
0	∓1.25000	∓1.22222	∓1.20000	∓1.18182	∓1.16667	0
1	1.15331	1.13083	1.11286	1.09815	1.08589	1
2	0.88627	0.87769	0.87082	0.86520	0.86052	2
3	0.51054	0.51912	0.52599	0.53161	0.53629	3
4	0.10677	0.12925	0.14722	0.16193	0.17419	4
5	−0.25000	−0.22222	−0.20000	−0.18182	−0.16667	5
6	−0.51127	−0.48879	−0.47082	−0.45611	−0.44385	6
7	−0.66504	−0.65646	−0.64959	−0.64397	−0.63929	7
8	−0.73177	−0.74035	−0.74722	−0.75284	−0.75753	8
9	−0.74881	−0.77129	−0.78926	−0.80397	−0.81638	9
10	∓0.75000	∓0.77778	∓0.80000	∓0.81818	∓0.83333	10
11	0.74881	0.77129	0.78926	0.80397	0.81638	11
12	0.73177	0.74035	0.74722	0.75284	0.75753	12
13	0.66504	0.65646	0.64959	0.64397	0.63929	13
14	0.51127	0.48879	0.47082	0.45611	0.44385	14
15	0.25000	0.22222	0.20000	0.18182	0.16667	15
16	−0.10677	−0.12925	−0.14722	−0.16193	−0.17419	16
17	−0.51054	−0.51912	−0.52599	−0.53161	−0.53629	17
18	−0.88627	−0.87769	−0.87082	−0.86520	−0.86052	18
19	−1.15331	−1.13083	−1.11286	−1.09815	−1.08589	19
20	∓1.25000	∓1.22222	∓1.20000	∓1.18182	∓1.16667	20

The factor $\frac{G}{g} \times \frac{v^2}{R}$ is a constant for a certain engine running at a given speed. The values P_a, in order to become transferred to the crank pin as effort at right angles to the radius will have to be multiplied by the coefficients of Table I. If

$$K = \frac{\sin(\omega \pm \lambda)}{\cos \lambda} \times (\cos \omega \pm \frac{R}{L} \cos 2\omega),$$

then the effort on the crank pin due to the inertia of the reciprocating masses is

$$T_a = K \times \frac{G}{g} \frac{v^2}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Table III. gives the values of K.

TABLE III.

Position of Crank.	Values of K.					Position of Crank.
	$L = 4R$	$L = 4\frac{1}{2}R$	$L = 5R$	$L = 5\frac{1}{2}R$	$L = 6R$	
0	∓0.00000	∓0.00000	∓0.00000	∓0.00000	∓0.00000	0
1	0.44146	0.42505	0.41058	0.39891	0.38946	1
2	0.62745	0.60945	0.59522	0.58386	0.57430	2
3	0.47491	0.47575	0.47656	0.47669	0.47683	3
4	0.10962	0.13146	0.14883	0.16279	0.17423	4
5	−0.25000	−0.22222	−0.20000	−0.18182	−0.16667	5
6	−0.44754	−0.43223	−0.41896	−0.40905	−0.39932	6
7	−0.45733	−0.46056	−0.46252	−0.46470	−0.46605	7
8	−0.34223	−0.35619	−0.36797	−0.37702	−0.38493	8
9	−0.17616	−0.18674	−0.19659	−0.20476	−0.21173	9
10	∓0.00000	∓0.00000	∓0.00000	∓0.00000	∓0.00000	10
11	0.17616	0.18674	0.19659	0.20476	0.21173	11
12	0.34223	0.35619	0.36797	0.37702	0.38493	12
13	0.45733	0.46056	0.46252	0.46470	0.46605	13
14	0.44754	0.43223	0.41896	0.40905	0.39932	14
15	0.25000	0.22222	0.20000	0.18182	0.16667	15
16	−0.10962	−0.13146	−0.14883	−0.16279	−0.17423	16
17	−0.47491	−0.47575	−0.47656	−0.47669	−0.47683	17
18	−0.62745	−0.60945	−0.59522	−0.58386	−0.57430	18
19	−0.44146	−0.42505	−0.41058	−0.39891	−0.38946	19
20	∓0.00000	∓0.00000	∓0.00000	∓0.00000	∓0.00000	20

The curve representing T_a is called the inertia curve, and its general shape is shown by Fig. 398.

Comparing Fig. 398 with Fig. 397, we find that the influence of the reciprocating masses is a beneficial one, since it tends to equalize the effect of the difference between the steam pressure during the earlier and the later part of the stroke, especially in

engines with a moderate speed and an early point of cut-off. But it often happens that the speed of an engine is so high that the steam pressure during a great part of the stroke is insufficient to produce an acceleration of the reciprocating masses corresponding to this speed, in which case the flywheel has to drag them along, and the bulk of the work done is thrown over upon the latter part of the stroke, producing great strains in the working parts of the engine, irregularities of motion, shocks when the pressure on the crosshead and crank pins does not change direction at the proper places, and so on. High initial

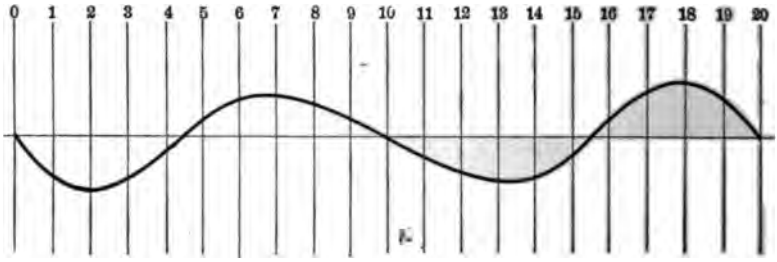


FIG. 398.

steam pressure and a sufficient amount of compression besides a minimum weight of the reciprocating parts is, in this respect, to be recommended for high-speed engines.

C.—Influence of weight of the reciprocating parts upon the rotative effect.

In vertical engines the weight of the piston, piston rod, and crosshead acts the same as an equal amount of steam pressure, adding to the work done during the downward stroke and subtracting from that of the upstroke. This action may be accounted for by adding and subtracting respectively a corresponding amount to and from the effective steam pressure P as measured from Fig. 396.

In a horizontal engine the dead weight of these parts is of no consequence. Remains the influence of the connecting rod, which is different in vertical and in horizontal engines.

Let in a vertical engine

G_c = the weight of the connecting rod;

l = the distance from the centre of crosshead pin to centre of gravity of connecting rod;

N_1 = the vertical, and
H = the horizontal component of t
due to G_c, and
N_2 = the pressure on the guide.
G_c, H, N_1, and N_2 (Fig. 399) co

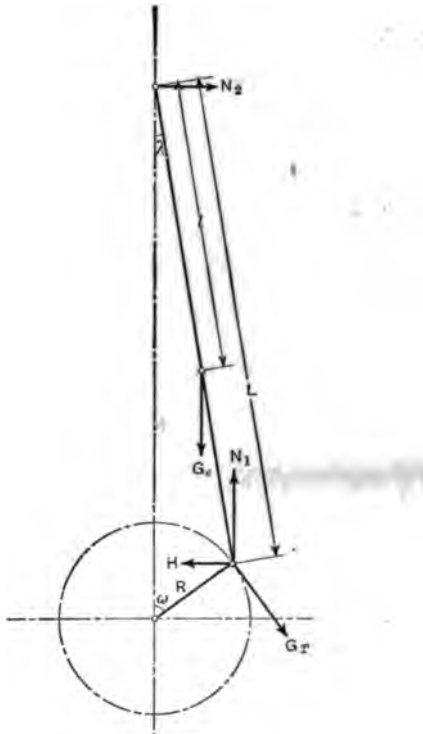


FIG. 399.

one plane which are in equilibrium. Therefore, by projecting and taking the moments, considering the centre of crank pin as a fulcrum, we have :

$$\begin{cases} N_2 - H = 0, \\ N_1 - G_c = 0, \end{cases}$$

and $$N_2 L \cos\lambda - G_c (L - l) \sin\lambda = 0,$$

which gives $$H = G_c \left(1 - \frac{l}{L}\right) tg\,\lambda.$$

The influence upon the rotative effect of N_1 may be N_T, of H may be H_T. Then we will have—

$$N_T = N_1 \cos(90° - \omega)$$
$$= G_c \sin \omega,$$
$$H_T = H \cos \omega$$
$$= G_c \left(1 - \frac{l}{L}\right) tg\lambda \cos \omega.$$

Let, further, the total influence of G_c be G_T, then

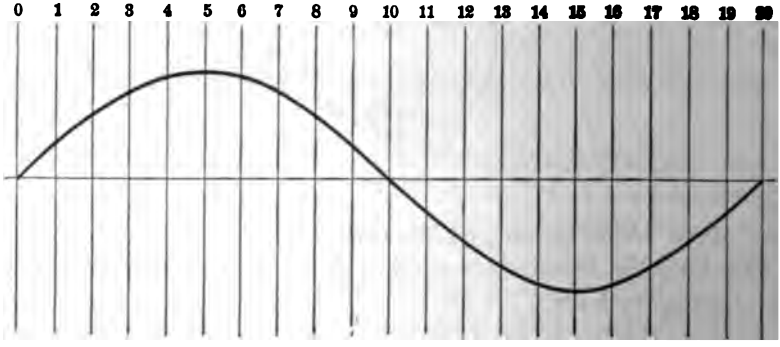
$$G_T = N_T + H_T$$
$$= G_c \left[\sin \omega + \left(1 - \frac{l}{L}\right) tg\,\lambda \cos \omega\right] . \quad . \quad . \quad . \quad (8)$$

For practical purposes the second term inside the bracket can be neglected as being very small, because at the two points, corresponding to $\omega = 90°$ and $270°$, where $tg\,\lambda$ has its greatest value $= \left(\frac{L^2}{R^2} - 1\right)^{-\frac{1}{2}}$, there $\cos \omega = o$, and $G_T = G_c$. Equation (8) therefore may be substituted by equation (8*a*):

$$G_T = G_c \sin \omega \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8a)$$

The curve representing G_T has an appearance shown by Fig. 400.

Since, in a horizontal engine, due to the sliding contact be-



Astrom

FIG. 400.

tween crosshead and guide, no horizontal strains can be created by the weight of the connecting rod, and N_2 is taken up by the guide, the only factor left is N_1 (Fig. 401).

$$N_1 = \frac{l}{L} G_c$$

By resolving N_1 into two components, one along the crank radius, the other at right angles to the same, the influence of

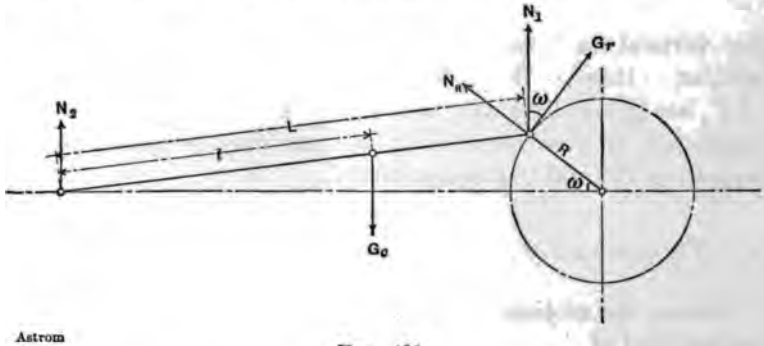


FIG. 401.

dead weight of connecting rod upon the rotative effect in a horizontal engine becomes represented by the equation—

$$G_T = \frac{l}{L} G_c \cos \omega \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The general appearance of the corresponding curve is shown by Fig. 402.

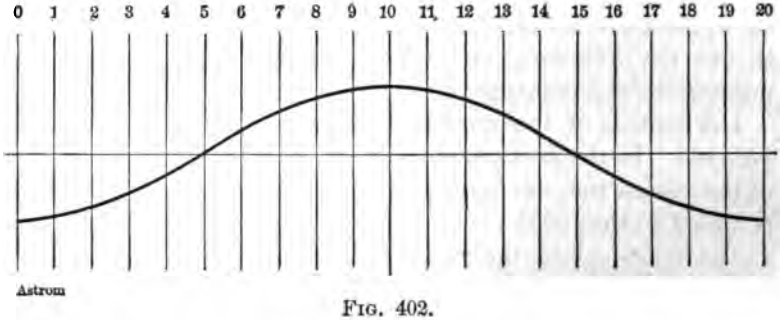


FIG. 402.

D.—Influence of weight of crank pin and unbalanced part of crank upon the rotative effect.

If the weight of these parts is G_o, the point of application of which is on a distance r from centre of shaft, the effort on the crank pin due to G_o is

$$T_o = \frac{r}{R} G_o \cos \omega \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

for horizontal, and

$$T_o = \frac{r}{R} G_o \sin \omega \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

for vertical engines. The corresponding curves have a shape similar to those of Figs. 402 and 400 respectively. The values of T_o are generally small, and this factor can therefore often be neglected, or a corresponding amount may be added to G_e in equations (9) and (8a) respectively.

E.—The influence of throw of connecting rod upon the rotative effect.

Among the motions which have to be dealt with in the steam engine, that of the connecting rod is by far the most complicated. The force of inertia of the rod due to its motion has in many cases a considerable influence upon the rotative effect. In order to approximately account for this factor, different writers have recommended different methods, but in most cases it is simply proposed to add a part varying from one-half to the whole of the mass of the rod to that of the reciprocating parts. But thereby no allowance has been made for the swinging motion or the throw. When, again, the subject is treated exhaustively, it often becomes so lengthy that its value for practical application is much reduced. The writer therefore proposes to use the following method, which, besides being short, also possesses the advantage of accuracy.

The motion of the connecting rod is divided into two components. In the first place the rod is considered as an extension of the piston rod, having no side motion, and the total mass of it is added to that of the reciprocating parts, as was done above. In the second place, the rod is considered as a pendulum, swinging about the crosshead pin as a fixed centre. The influence of this motion is calculated. Thereby the total influence of the rod has been considered.

In Fig. 403, let L, R, r, and ω stand for the same quantities as before, and let C_1, and C be the centres of crank pin, crosshead pin, and shaft respectively.

C_1 rotates in a circle of the radius R at a rate of n revolutions per minute. Its velocity is

$$v = \frac{\pi R n}{30}$$

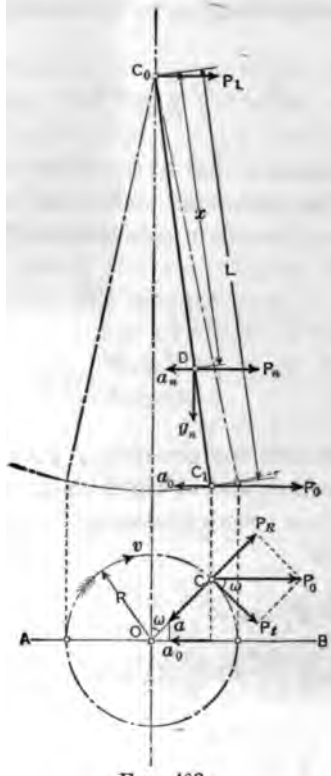


FIG. 403.

per second. The total acceleration of C is

$$a = \frac{v^2}{R},$$

which is always directed towards O. The projection of a upon the diameter $\overline{AB}$ is

$$a_0 = \frac{v^2}{R} \sin \omega,$$

which also is the total acceleration of C_1 since C_0 is considered a fixed centre.

If the connecting rod is divided into a number of parts, and the weight of one of these parts is g_n, and if, further, x is the distance from the centre of gravity of the part considered to the centre of crosshead pin, this part of the rod will produce a force

P_n at the point D at right angles to the centre line of the engine, and we have

$$P_n = \frac{g_n}{g}\frac{x}{L}\frac{v^2}{R}\sin\omega \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where g is the acceleration due to the force of gravity. P_n has a component P_1 at the crosshead end of the rod, which is taken up by the guide, and another component P_o acting upon the crank pin.

$$P_o = \frac{x}{L}P_n$$
$$= \left(\frac{x}{L}\right)^2 \frac{g_n}{g}\frac{v^2}{R}\sin\omega.$$

P_o is resolved into two components, P_R and P_t in the directions of the crank radius, and at right angles to the same respectively. Of those, P_R is counterbalanced by an equal pressure on the bearing at O, and

$$P_t = P_o\cos\omega$$
$$= \left(\frac{x}{L}\right)^2 \frac{g_n}{g}\frac{v^2}{R}\sin\omega\cos\omega$$
$$= \frac{1}{2}\left(\frac{x}{L}\right)^2 \frac{g_n}{g}\left(\frac{\pi n}{30}\right)^2 R\sin 2\omega \quad . \quad . \quad . \quad . \quad . \quad (13)$$

If we introduce

$$k = \frac{1}{2}\frac{R}{L^2}\left(\frac{\pi n}{30}\right)^2$$
$$= 0{,}0054775\,\frac{n^2 R}{L^2},$$

which is a constant for a certain engine running at a given speed, and if P_T is the total influence of the rod upon the rotative effect, we will have

$$P_T = \Sigma(P_t)$$
$$= k\sin 2\omega\,\Sigma_o^L\left(x^2\frac{g_n}{g}\right), \text{ or}$$
$$P_T = k\sin 2\omega\, I \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

where I is the moment of inertia of the rod about the axis of the crosshead pin.

By calculating the values of P_T we get a curve, shown in Fig. 404.

It may here be of some interest to notice the general shape of a curve representing the combined effect of throw and dead-weight of the connecting rod. For a horizontal engine this is shown by Fig. 405, and for a vertical engine by Fig. 406.

By the addition of all the above obtained curves we get the final curve of rotative effect (Fig. 407). The mean effort T_m will again, as before, check the correctness of the calculations according to equation (3), because none of the factors which have brought about a change of shape of the original curve of steam effort (Fig. 397) has added to or subtracted anything from the work done by the steam.

The Load Curve.

Besides the curve of effort there is also needed a load curve, representing the total load to be overcome by the engine, transferred to the crank pin. The total load is the sum of the working load and the friction load.

Here, as above, one revolution only of the engine will be considered, and the assumption made that the work done during that revolution is the same and done in the same way as during the previous and the successive revolutions.

In the case of an engine driving a centrifugal pump, a fan, a generator of electricity, or similar apparatus the curve of working load becomes a straight line. In the case of a pumping engine or a gas compressor engine of common type, the curve of working load is designed by aid of equation (2). In the former case the curve will be similar to that of steam effort of an engine taking steam full stroke; in the latter case it will resemble the reversed curve of steam effort of an engine with a cut-off.

Also the shape of the curve of friction load depends upon the style of engine. The friction of the reciprocating parts will render a curve according to equation (2), whereas the resistance of the flywheel and that in the main bearings will add to the load curve a constant amount. In a pumping engine, for instance, the bulk of the friction is caused by the reciprocating parts, and can therefore, by being added to the pressure on the plunger, conveniently be transferred to the crank pin together with the working load.

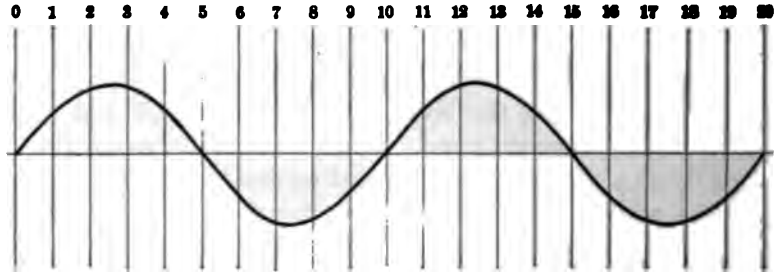


FIG. 404.

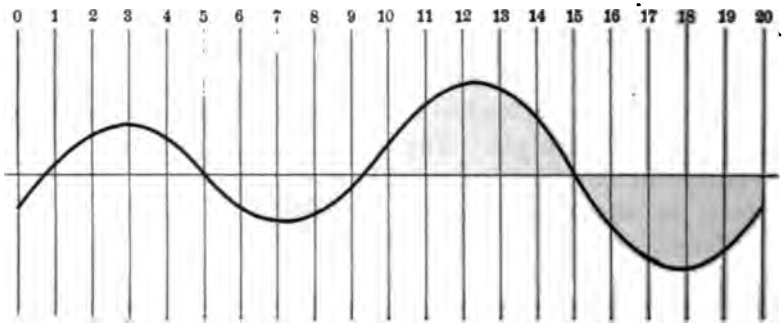


FIG. 405.

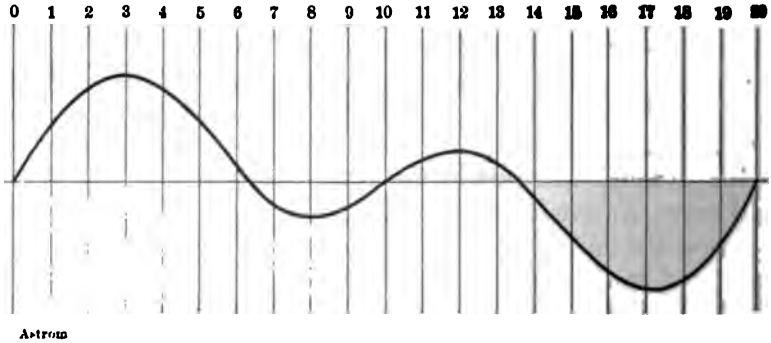


FIG. 406.

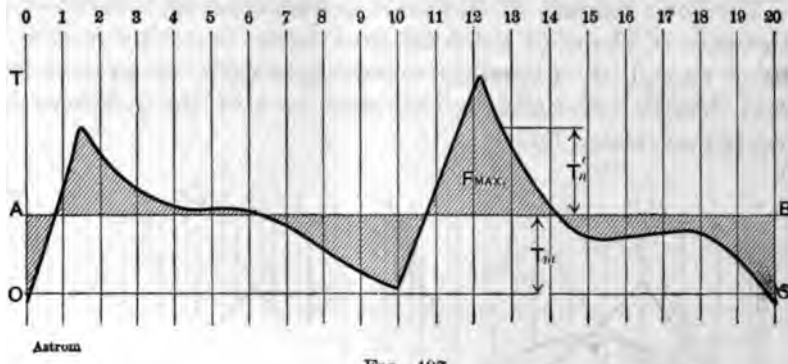


FIG. 407.

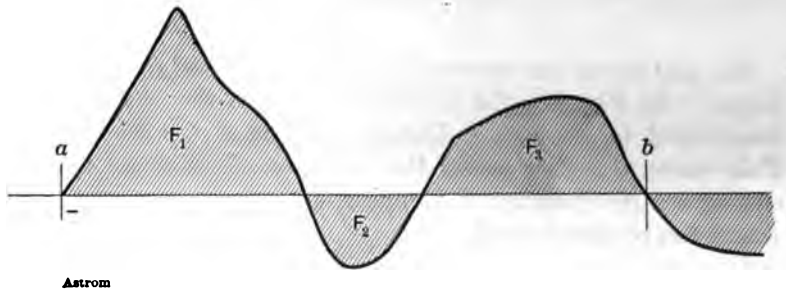


FIG. 408.

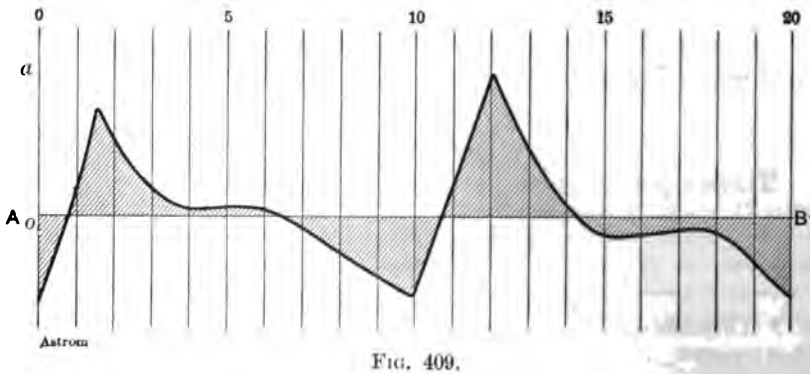


FIG. 409.

The total amount of friction is generally small, and the disturbance of shape of the total load curve caused by it is not large enough to make it necessary, generally, to go very far into details, especially as the main part of the influence is readily accounted for.

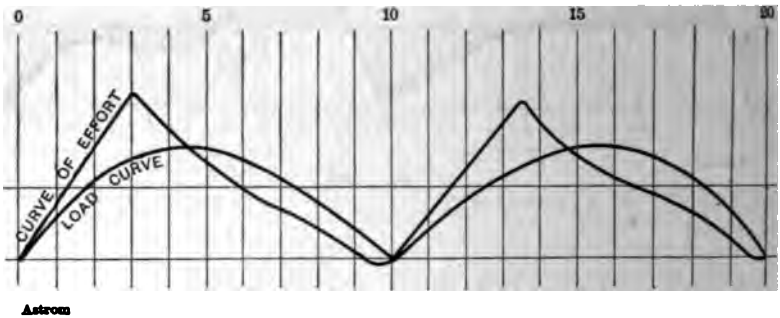


FIG. 410.

Fig. 410 shows the curves of effort and of load of a pumping engine. In Fig. 411 the difference between the two has been transferred to a straight line, representing the mean effort. This curve, therefore, gives the variation of effort on crank pin during one revolution of the engine, and from the same the flywheel can be determined.

The General Method of arriving at the Flywheel Dimensions.

Let v, as before, be the mean velocity of crank pin, and δ the degree of irregularity of v, so that

$$\delta = \frac{v_{max} - v_{min}}{v},$$

and approximately

$$v = \frac{v_{max} + v_{min}}{2}.*$$

These equations give

$$\delta v^2 = \frac{v^2_{max} - v^2_{min}}{2}.$$

* It depends upon circumstances how close this approximation is. The writer has repeatedly found that this assumption would have led to great errors.

If F_{max} is the greatest of the surfaces enclosed between the variation curve of effort and the load curve ($\overline{AB}$ in Fig. 407), thus representing the maximum of inertia to be at one time stored by (or, if the surface is below $\overline{AB}$, to be extracted from)

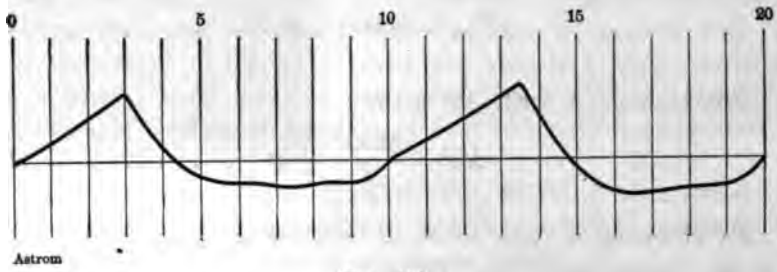


FIG. 411.

the flywheel, and M is the sum of the rotative masses, reduced to the crank pin, then

$$F_{max} = M \frac{v^2_{max} - v^2_{min}}{2}$$
$$= M\delta v^2,$$

which gives

$$\delta = \frac{F_{max}}{Mv^2} * \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

The work done by the engine per revolution is

$$W = 2\pi R T_m.$$

If we write

$$F_{max} = \varphi 2\pi R T_m$$
$$= \varphi W,$$

then φ is a coefficient, independent of the work done by the engine, but depending only upon the way in which the pressure on the crank pin is distributed during one revolution, and gives

* Suppose a case represented by Fig. 408. The greatest surface $+ F_1$ is followed by a comparatively small surface $- F_2$, after which comes $+ F_3$. If $| F_3 | > | F_2 |$, then between the points a and b an energy represented by $(F_1 - F_2 + F_3)$ has been stored in the flywheel, whereas according to the general method only F_1 has been considered. This shows another defect of the method.

the work represented by F_{max} in per cents. of the total work W. Now

$$N = \frac{2\,\pi\,RT}{33000}\,n,$$

and consequently

$$F_{max} = 33000\,\frac{N}{n}\,\varphi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Combining (15) with (16) gives

$$Mv^2 = \frac{33000}{\delta}\,\frac{N}{n}\,\varphi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

By choosing a value for δ, M becomes determined, and from M the dimensions of the flywheel.

Some values of δ, taken from several text-books, will be given below.

For stamps, crushers, etc.	$\frac{1}{5}$		
For saw-mills and pumping engines	$\frac{1}{10}$	$\frac{1}{30}$	
For weaving machines and paper mills	$\frac{1}{15}$	$\frac{1}{40}$	
For flour mills	$\frac{1}{15}$	$\frac{1}{40}$	$\frac{1}{50}$
For spinning machines for coarse to middle fine yarns	$\frac{1}{15}$	$\frac{1}{50}$	$\frac{1}{60}$
For spinning machines for finer yarns	$\frac{1}{20}$		$\frac{1}{150}$
For belt-driven dynamo machines		$\frac{1}{150}$	
For directly coupled dynamo machines	$\frac{1}{200}$	$\frac{1}{300}$	$\frac{1}{600}$

There is a marked tendency to reduce these coefficients. The later authors give smaller values than the older ones, and we also find the modern engines generally to be fitted with heavier flywheels than the average values would call for. The last coefficient, perhaps the most important one nowadays, is especially uncertain, having such a wide range. But in more delicate cases the use of a figure merely grasped from a table is perhaps not the safest or the best practice, especially as it has been found that a certain value of δ, giving good results with one engine, does not always give the same satisfaction with another engine doing the same kind of work.

Another Method of Calculating the Flywheel.

It is sometimes desirable to have a more defined quantity by which to determine the degree of variation of an engine than the amount of inertia possessed by the flywheel at different times. Such a quantity offers itself in the displacement of

crank pin. If the circumference of the crank-pin circle is the unit by which the variation of the engine is measured, then δ will mean a certain percentage of $2\pi R$. In that case, if a certain value of δ has been found to give satisfaction for a certain kind of work, the same coefficient also will cover all cases of the same kind, and all uncertainty is at once done away with. Then the weight of the wheel does not have to be determined with a liberal hand, so as to make sure that it will be "plenty large enough," but it can be made closely to satisfy a particular demand.

After the variation curve of effort (Fig. 407) has been found, there is comparatively but little work left in order to arrive at a curve representing the crank-pin displacement.

A certain mass M is assumed to be located at the crank pin. Call an ordinate to the curve of effort in a certain point T'_n. Then

$$a_n = \frac{T'_n}{M},$$

where a_n is the acceleration of crank pin in the point considered, due to T'_n. a_n is positive or negative when T'_n falls above or below $\overline{AB}$ respectively. In the former case there is an acceleration, in the later case a retardation of speed. Thus the variation curve of effort also represents the acceleration of crank pin to a scale which depends upon M.

Suppose a variable acceleration a to be represented as a function of time by some equation

$$a = \chi(t).$$

If the variable speed due to a is u, the formula

$$a = \frac{du}{dt}$$

gives

$$du = \chi(t)\,dt,$$

and

$$u = \int \chi(t)\,dt + c.$$

If besides two corresponding values u_o and t_o of speed and time are known, we get, after determination of c, as an expression for the velocity of the motion,

$$u - u_o = \int_{t_o}^{t} \chi(t)\,dt$$

$$= \int_{t_o}^{t} a\,dt.$$

This last integral represents the surface enclosed by the t-axis, two ordinates at t' and t'', and the part of the curve $\alpha = \chi(t)$ intersected by said ordinates. Consequently, by integration of the curve of acceleration the variation curve of velocity is found.

In Fig. 409 the ordinates on even intervals give the acceleration at equidistant points of the crank-pin circle. Therefore, in order to apply the above to our case, the abscissa axis must be made to represent time instead of space, or, if it is assumed

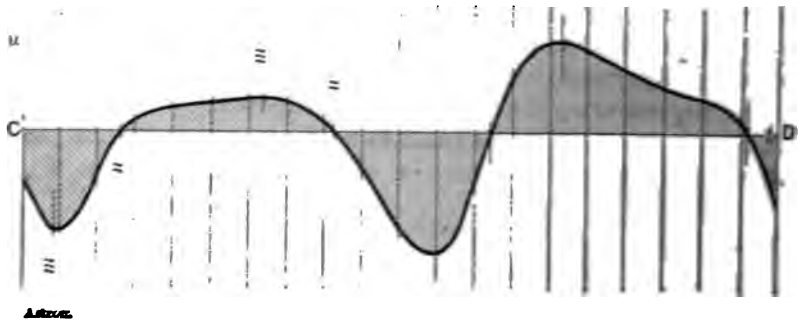


FIG. 412.

to represent time (which of course is very nearly correct), a correction of the error thus committed can, in case extreme accuracy is desired, be made. This is practically done by first integrating the curve of acceleration, and, under the assumption that the abscissa axis represents time, getting the quantities u_0, u_1, u_2, . . . u_{n-1}, u_n, by which the velocity is increased (respectively decreased) from one interval to the other. But the time needed by the crank pin to cover each one of the equal parts of its path stands in inverse proportion to the velocities with which these spaces are passed. If, therefore, a new system of ordinates is raised upon a line CD (Fig. 412), the distances between which are in direct proportion to the quantities

$$\frac{1}{1 + \frac{u_1}{v}}$$

$$\frac{1}{1 + \frac{u_1 - u_2}{v}}$$

$$\frac{1}{1+\frac{u_1+u_2+u_3}{v}}$$

$$\cdots\cdots\cdots\cdots$$

$$\cdots\cdots\cdots\cdots$$

$$\cdots\cdots\cdots\cdots$$

$$\frac{1}{1+\frac{u_1+u_2+\cdots+u_{n-1}}{v}}$$

$$\frac{1}{1+\frac{u_1+u_2+\cdots+u_n}{v}},$$ *

and if on these ordinates, raised through points now representing the times actually needed for covering the equal spaces of Fig. 407, the values obtained by integrating the acceleration curve are marked off, the curve through those points will represent the variation of velocity of crank pin during one revolution of the engine.

Since $\overline{AB}$ (Fig. 407) is the mean of the curve, the sum

$$u_1 + u_2 + u_3 + \cdots u_{n-1} + u_n = 0,$$

and

$$\frac{1}{1+\frac{u_1+u_2+\cdots u_n}{v}} = 1,$$

which shows that, under the assumption made on page 968, the crank pin during successive revolutions of the engine always passes a certain point with the same velocity, or that the variation of velocity is periodical, each period being one revolution.

The relations

$$a = \frac{du}{dt},$$

$$u = \frac{ds}{dt}$$

and consequently

$$a = \frac{d^2s}{dt^2}$$

* In order to make such a correction possible on the drawing-board, a quite large scale has to be used for time.

show that the curve of displacement of crank pin is to be gotten from the curve of acceleration by a double integration of the same. The first integration gave the variation curve of velocity (Fig. 412). Since the abscissæ here signify time, the second integration can be performed directly. The result is the curve of displacement of crank pin, caused by the variation of effort (Fig. 413).

The abscissæ of Fig. 413 represent time. The ordinates, therefore, determine how much the location of the crank pin at every moment of one revolution differs from what it would be if the speed were constant and equal to v.

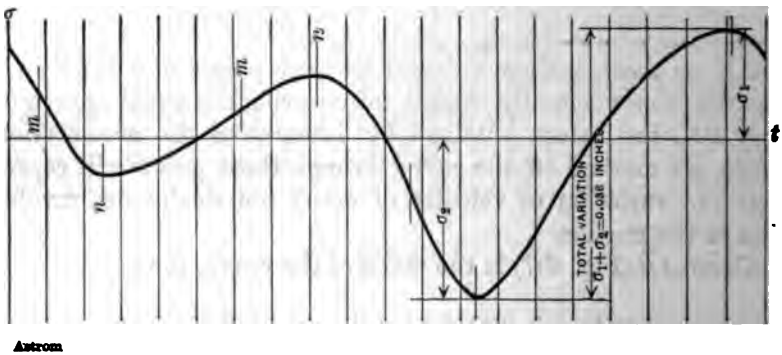


FIG. 413.

By the expression "to integrate a curve" here is meant, that the abscissa representing one revolution by ordinates is divided into a convenient number of parts (say 20 or 40) and the surfaces enclosed by each two ordinates, the intersected part of the curve, and the abscissa axis are measured in succession, and the values obtained used for plotting a new curve. This can accurately be performed with a planimeter.

When deriving one curve from the other by integration of the enclosed surface, as above, there is always a number of points of special interest. Where the primary curve has a vertex (maximi or minimi-point) the secondary curve has a point of inflexion, and where the former curve intersects the abscissa axis, there the later one has a vertex (points marked m and n respectively in Figs. 412 and 413). This feature is valuable for getting the correct curvature.

Each one of the above curves represents its quantity, acceler-

ation, velocity, or displacement in a scale, which depends upon the mass M assumed at the crank pin and upon the scales in which the curves are designed.*

The Figs. 397, 398, 402, 404, 405, 407, 409, 412, and 413 are taken from a horizontal condensing engine, having a ratio between crank radius and length of connecting rod of 1 to 5. The steam card and other data of this engine are given by Fig. 396.

Assuming in this case the mass of 250,000 pounds as concentrated at the crank pin, Fig. 413 gives the total displacement of crank pin.

$$\sigma = \sigma_1 + \sigma_2 = 0.036 \text{ inch},$$

corresponding to 0.03183 of one per cent. of the crank-pin circle.

If this engine, for instance, is to drive a directly coupled alternating current generator, which is to operate in parallel, the variations of frequency must be limited to a certain maximum amount, and a flywheel must be provided of sufficient inertia to accomplish this limitation. Suppose that the generator is a 30-pole machine. The usual way of fixing the limit of angular variation allowable in a generator is to divide the angle corresponding to two poles of the machine into 360 parts, which may be called "pole-degrees." †

If it is decided that in this case the total variation shall not exceed 8 pole-degrees, we must have

$$\begin{aligned} \sigma &= \frac{8}{360 \times 30} \times 2\pi R \\ &= 0.08373 \text{ inch} \\ &= 0.074 \text{ per cent.} \end{aligned}$$

From the way the curve of displacement has been derived from the curve of acceleration it is evident that the amount of

* In the case illustrated, for instance, the rectified crank-pin circle and the time of one revolution were represented by lines 10 inches long. Therefore, at a speed of 100 revolutions per minute, one inch of the abscissa axis represents 0.06 second [t]. In Fig. 407 the scale of effort was 1 inch = 5000 lbs. [T], and with a mass $M = 7773 \frac{\text{lbs. sec.}^2}{\text{ft.}}$ (equal to the mass of 250,000 lbs.) assumed at crank pin, the equation $u = \frac{T}{M} t$ gives, as the scale of velocity, one square inch (of measured surface) = 0.0386 feet per second.

† These quantities are often referred to simply as "degrees," which is deceiving and probably is a consequence of the words "of phase departure" having been left out.

displacement is in proportion to the mass M assumed at the crank pin. Therefore the mass needed at crank pin to accomplish the desired degree of regulation in this case is

$$M_o = \frac{0{,}03183}{0{,}074} \times 7773$$
$$= 3343 \frac{\text{lbs. sec.}^2}{\text{ft.}},$$

which is the mass of 107,511 pounds. If this weight is reduced to the rim of a flywheel, the effective diameter of which is 10 feet, the weight of this rim becomes

$$W = \left(\frac{18}{60}\right)^2 \times 107511$$
$$= 9676 \text{ lbs.}$$

This is under the assumption that the flywheel rim is the only revolving mass with any influence upon the regulation. The inertia of the arms of a wheel adds a small amount to that of the rim, but of more influence is, for instance, the revolving field of a generator, which may allow a considerable reduction in flywheel weight to be made.

Compound Engines.

In compound engines the curves of effort of the high and low pressure sides are designed as for separate engines. They are then added together in a position corresponding to the crank angles. From the resulting curve of total effort, combined with the load curve, the variation curves of effort and velocity are designed, and finally the curve of displacement of crank pin.

Fig. 414 shows the curves of steam effort (marked ————), of inertia (— - - - - - - -), of influence of connecting rod (— · — · · — · · —), and the combined curve of effort (drawn in full) of the high-pressure side, Fig. 415 of the low-pressure side of an 18-inch and 34-inch by 36-inch cross compound condensing engine, developing 725 indicated horse-power at a speed of 150 revolutions per minute. The cranks are set at right angles, the high-pressure engine having the lead. It is of special interest here to notice the influence of the reciprocating masses.

Fig. 416 shows the variation curve of effort for this engine. The variation of velocity is represented by Fig. 417, and, assuming the

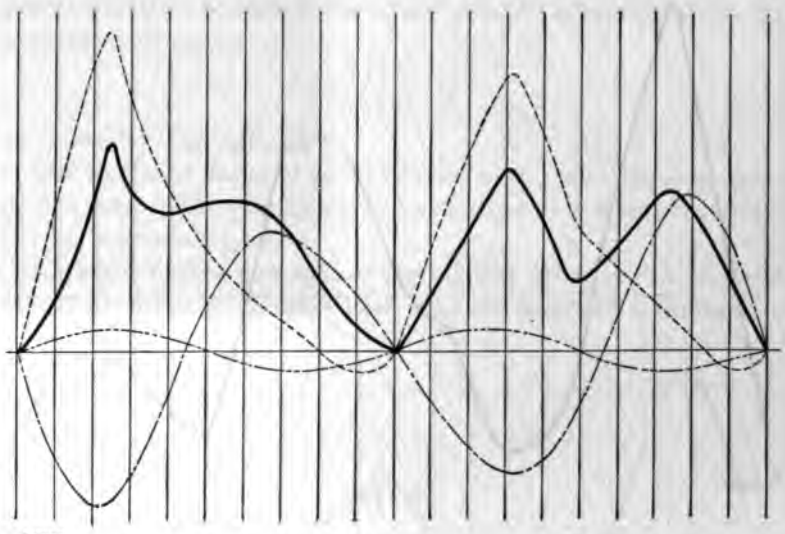


FIG. 414.

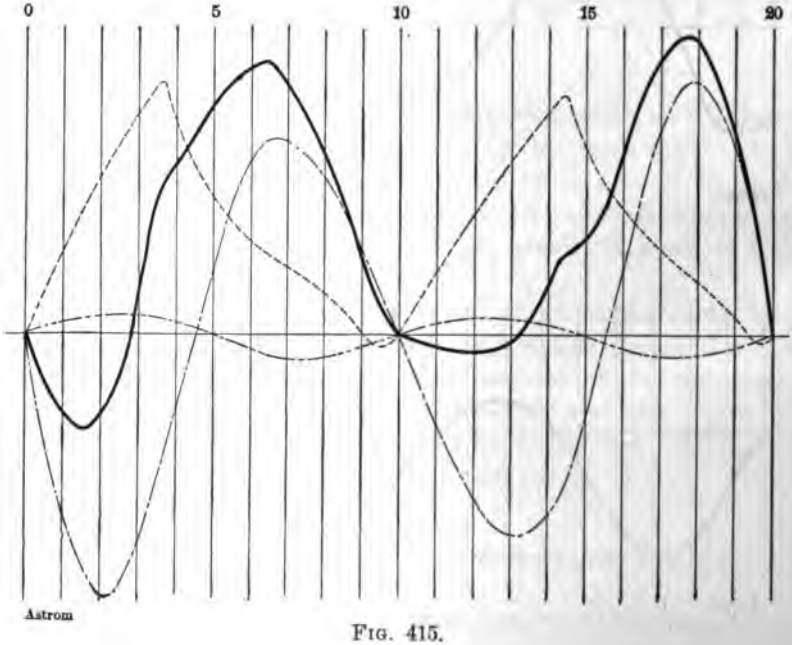


FIG. 415.

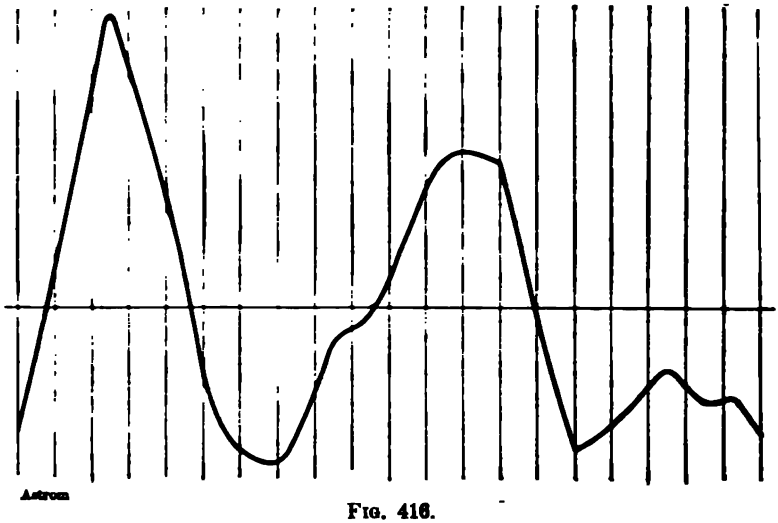


FIG. 416.

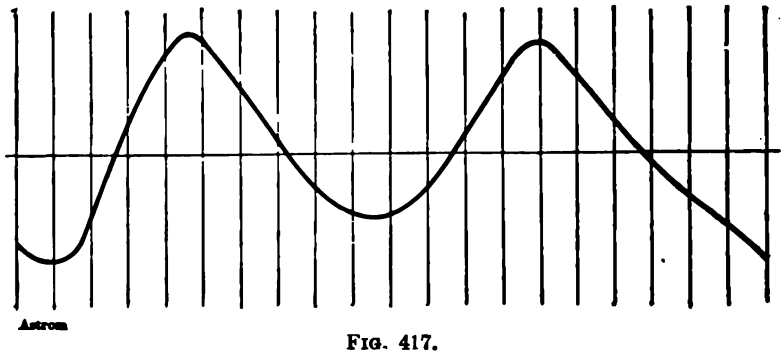


FIG. 417.

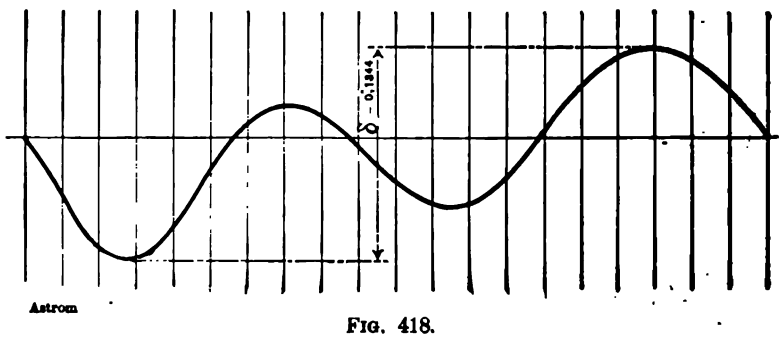


FIG. 418.

mass of 100,000 pounds at the crank pin, the total crank-pin displacement becomes

$$\sigma = 0.1344 \text{ inch}$$
$$= 0.1188 \text{ per cent.},$$

as shown by Fig. 419.

The variation curve of effort has not a very smooth appearance in this case. The question then naturally arises whether it could not be improved upon.

Without in this connection paying any attention to changes, eventually improvements, which could be made by reductions of

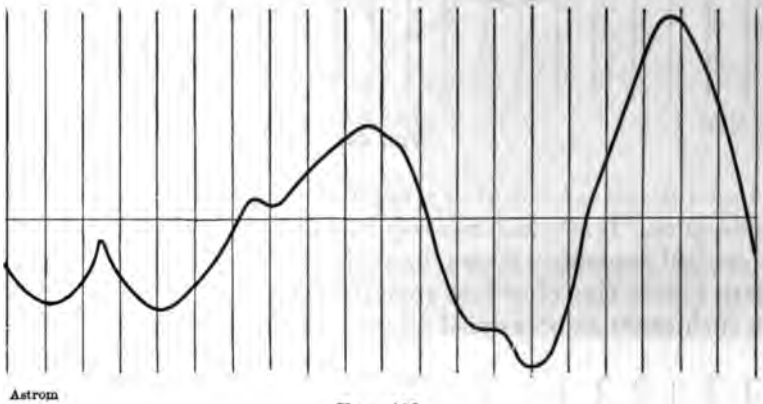


FIG. 419.

or additions to the weight of the reciprocating parts, we will here only consider the influence of a change of the crank angle. And it will be found that here, as in every case, there is a certain crank angle which will, more than others, reduce the variation of effort. It also will appear that this crank angle usually is more or less remote from 90 degrees.

Fig. 419 shows the variation curve of effort for the compound engine referred to greatly improved by the choice of a crank angle of 144 degrees, and by giving the low-pressure engine the lead.

The resulting variation curve of velocity and the curve of crank-pin displacement are shown by Figs. 420 and 421 respectively. The total variation has been reduced to

$$\sigma = 0.1055 \text{ inch}$$
$$= 0.0933 \text{ of one per cent.}$$

This represents a gain of 21.51 per cent. by which amount the

weight of the flywheel can be reduced, keeping the variation the same in both cases.

Knowing the action of the regulator employed we can, in cases where sudden changes of load are liable to occur, draw a diagram representing the variation of effort and get the consequent crank-

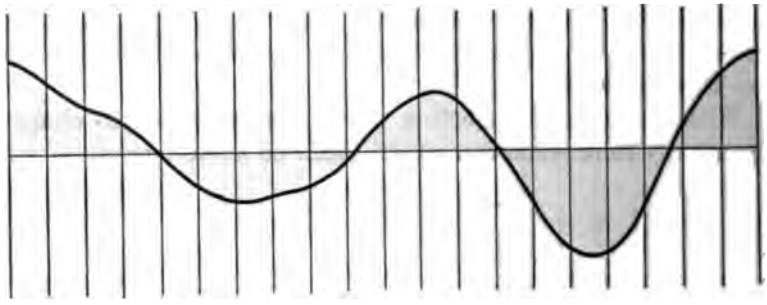


FIG. 420.

pin displacement, covering a number of successive revolutions of the engine. It is sometimes required to do this for engines driving electrical apparatus, where the engine, more or less suddenly, may have to take care of or lose a considerable part of the load. But in such cases an occasional slight increase of variation during a

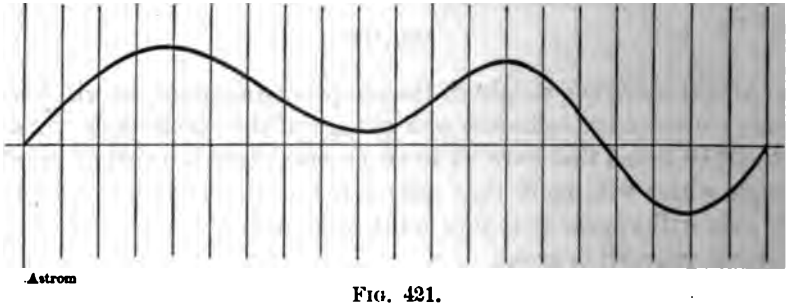


FIG. 421.

few revolutions cannot be altogether avoided, although a certain maximum disturbance may be observed.

The number of horse-powers developed by an engine does not, within quite large limits, appreciably affect the amount of variation as calculated for normal or average conditions of load. As an illustration of this, Fig. 422 may serve, which represents the curves of effort of a 44-inch and 86-inch by 60-inch vertical cross compound condensing engine, developing 3,650, 5,050, 6,070, and

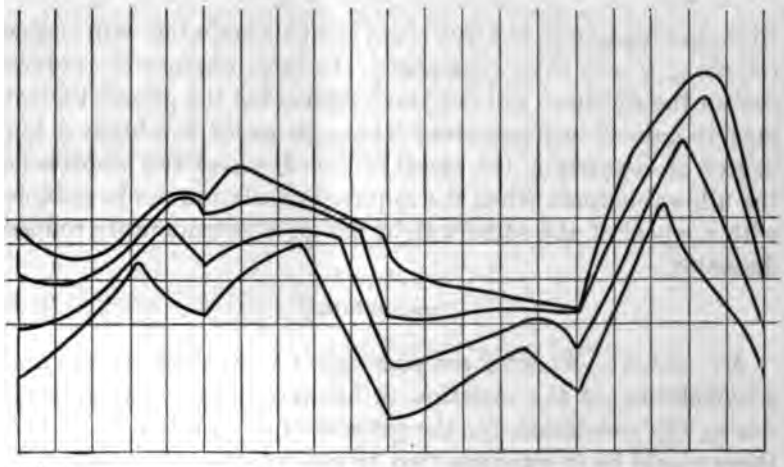


FIG. 422.

6,820 indicated horse-powers, respectively, at a speed of 75 revolutions per minute. The cranks are set at 90 degrees, high-pressure engine leading.

Fig. 423 shows the curves of effort of the same engine under the

FIG. 423.

same conditions of load, but with the low-pressure crank in the lead by 120 degrees. The improvement is obvious.

By using the crank angle which gives the most uniform rotative effect, the displacement of crank pin has been found to get reduced by 15 to 30 per cent. Then the engine has not the greatest pos-

sible starting power, but this is not as a rule essential with engines requiring a very close regulation. In large engines the reduced cost of the flywheel will cut some figure, but the greatest advantage is gained in those cases where, in order to obtain a high degree of regulation, the speed of the flywheel rim approaches the allowable limit, when the required regulation can be obtained with a wheel of the same weight but of a considerably reduced diameter.

DISCUSSION.

Mr. Abbott.—About three years ago I was called upon to make a calculation of the variation in angular velocity of an engine during one revolution, for the purpose of determining what error there would be in running two triple-expansion engines driving direct-connected alternating current generators which were to be run in parallel.

I looked about for some literature on the subject, and failed to find anything. I groped about in darkness for a time, and finally evolved a method of determining this variation, which I have since applied to a 3,500 horse-power vertical compound Allis engine, which is now being built for the Chicago Edison Company. This method, while not so analytical as the one which has just been presented, might possibly be of interest, as it offers a simple draughting-room method for determining with reasonable accuracy the angular variation. The method as applied to the engine above mentioned is as follows:

First: Determine the weights of the reciprocating parts of the engine, also the weights of the revolving parts reduced to a common moment at the radius of the crank-pin circle. The weight of the connecting rod is put half in each of these two divisions unless the crank end is much heavier than the crosshead end, in which case it is divided proportionately. To reduce the different revolving weights to an equivalent mass at crank radius, we use the formula—

$$W = w_1 \frac{r^2}{r_1^2} + w_2 \frac{r^2}{r_2^2} \cdot \cdot \cdot + w_x \frac{r^2}{r_x^2}.$$

From the determined weight of the reciprocating parts we will next construct a curve showing the varying pressure which this weight exerts upon the crosshead pin during a stroke. This is determined graphically as follows:

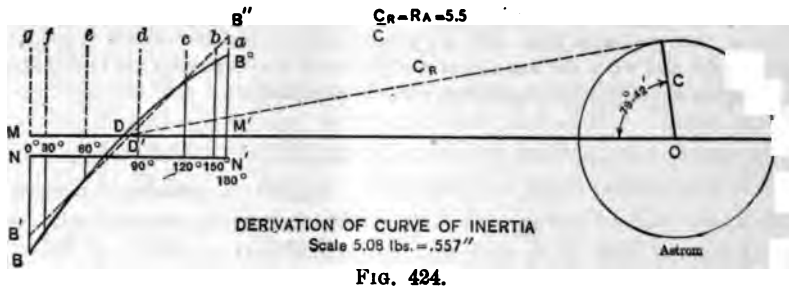


FIG. 424.

WEIGHT IN POUNDS OF RECIPROCATING PARTS.

Crosshead		
Connecting rod total = 6,500 reciprocating	8	"
Reciprocating weight common to all cylinders		"
High-pressure piston = 2,120; rod = 1,466; piston-rod = + 10,213 =	13,799	"
Low-pressure piston = 8,040; rod = 2,042; piston-rod = 10,082 + 10,213 =	20,295	"

DERIVATION OF CURVE OF INERTIA.

Stroke	
R. P. M.	
$V = \frac{5\ \pi\ 75}{60}$	19.63
V^2	385.34
R [of crank] =	2.5 feet
W = weight of reciprocating parts on one crank.	
F_o = inertia of reciprocating parts at dead centre (connecting rod infinite) $= \frac{W}{g} \times \frac{V^2}{R} =$	4.79 W.
Crank	30 inches.
Connecting rod	165 "
$\frac{\text{Crank}}{\text{Connecting rod}} = \frac{R}{L}$	$\frac{1}{5.5}$

Lay off MM' to represent stroke of piston.

Lay off MB' and $M'B''$ to represent pressure per pound of reciprocating parts at dead centres.

Straight line joining $B'\ B'' =$ inertia curve with infinite rod.

$D =$ position of piston when rod is tangent to crank circle.

$$MB = MB' + \frac{MB'}{R_a}. \quad R_a = \frac{\text{connecting rod}}{\text{crank}} = 5.5.$$

$$M'B^\circ = M'B'' - \frac{M'B''}{R_a}.$$

Curve BDB° should be a parabola, but is here an arc of a troduces no practical error, however.

Lay off NN' parallel to MM' a distance below MM' represented by one pound to scale; then ordinates from NN' are proportional to combined effects of weight and inertia, and when the number of pounds which they represent are multiplied by weights of reciprocating parts, give values in tables.

		High Pressure.	Low Pressure.
	Weight.	13,799	20,698
Ordinate a = inertia at 180°	a	69,000	101,475
" b = " 150°	b	63,480	96,357
" c = " 120°	c	49,680	78,081
" d = " 90°	d	24,840	36,581
" e = " 60°	e	− 12,420	18,265
" f = " 30°	f	− 48,300	71,082
" g = " 0°	g	− 64,860	95,366

Referring to Fig. 424, draw the line MP, representing in extent the combined length of the connecting rod and the piston travel. From the point O with radius OP strike a circle representing the crank travel. From the other end of the line MP lay off the distance MM', representing the piston travel. Now, assuming that a weight W equal to that of the reciprocating parts were concentrated at the centre of the crank pin, and were made to travel in the crank-pin circle at the same number of revolutions as the engine is to run, their centrifugal force calculated from the formula $\frac{W v^2}{gr}$ would be, in this case, $4.79 \times W$. If again we assume that instead of travelling in the crank-pin circle, this weight were attached to the end of a connecting rod of infinite length, this formula would still represent the momentum, or inertia, at the instant of passing the dead centres. This inertia force would, of course, act in opposite directions at the opposite ends of the piston travel, and would be zero at the middle of the stroke. We therefore have three points of the inertia curve for a connecting rod of infinite length. Referring to Fig. 424, lay off at right angles to and below the line MM' the distance MB', representing the inertia at one end of the stroke, and the equal distance $M'B''$ above the line, representing the inertia at the other end of the stroke, and draw a straight line, which will pass through the centre of the piston travel D' connecting these three points. This line $B'D'B''$ represents the inertia curve for the reciprocating parts with the connecting rod of in-

finite length. To correct this curve for a rod $5\frac{1}{2}$ cranks in length, lay off on line $M'B''$ the distance $B''B^{\circ}$, representing $\frac{1}{5.5}$ of the distance $M'B''$. Again, on the line MB' produced, lay off $B'B$, which is also $\frac{1}{5.5}$ of the length of the line MB'. These points B and B° are two points on the curve of inertia for a connecting rod of $5\frac{1}{2}$ cranks in length. To find the third point draw a line of the length of the connecting rod tangent to the crank-pin circle, and where this intersects the line MM' will be the third

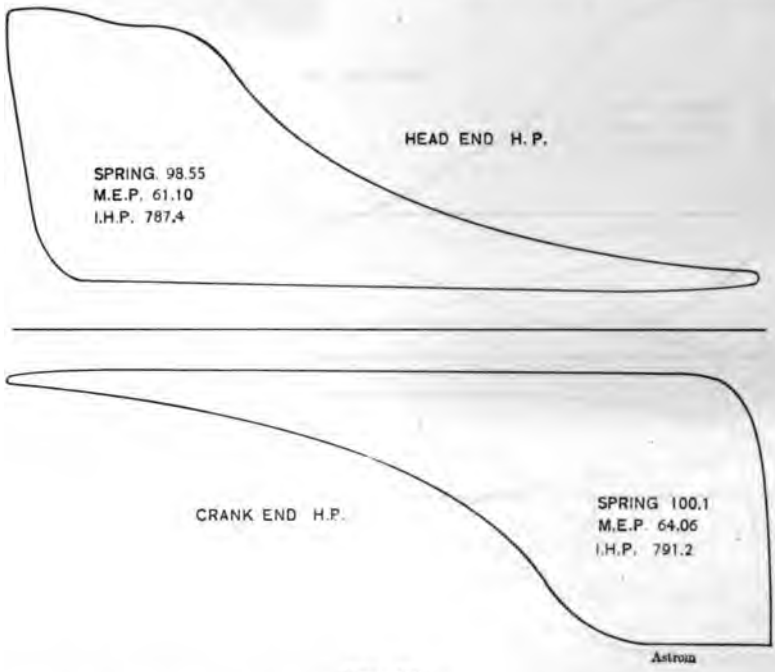


FIG. 425.

point on this inertia curve. Now strike the arc of a circle through the three points B, D, B°, and this will be the inertia curve for a connecting rod $5\frac{1}{2}$ cranks long; and the ordinates included between the line MM' and this curve represent the pressures upon the crosshead pin at the different points of the stroke.

The engine under consideration being of the vertical type, lay off the line NN' below the line MM' at a distance representing the weight of the reciprocating parts. Ordinates then measured above or below NN' represent the pressures upon the crosshead

pin due to both the inertia and the weight of the reciprocating parts.

Take now a pair of indicator diagrams, as shown in Fig. 425, and combine them so as to eliminate the back pressures, producing a curve representing the net pressure per square inch upon the piston. This curve I do not show, but instead I show a similar curve A in Figs. 427 and 428, obtained by multiplying

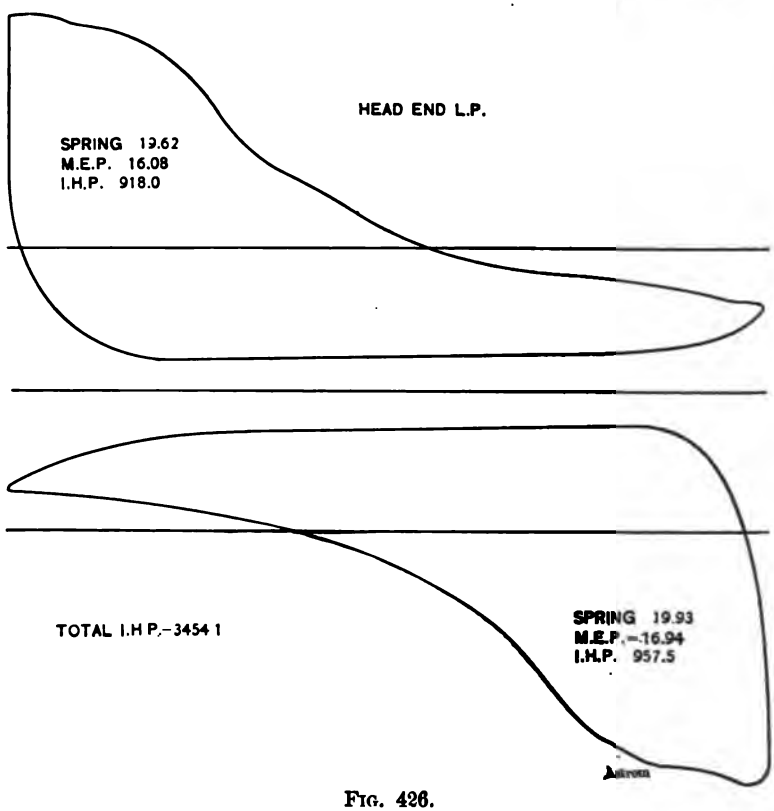


FIG. 426.

the ordinates of the curve not shown by the number of square inches in the piston (correcting for area taken out by the piston rod), and this curve represents the entire pressure upon the crosshead pin, due to steam pressure, upon a scale of 100,000 pounds per inch. Now draw in the inertia curve B to the same scale, and combine the curve A with the curve B, producing the curve C, all in Fig. 427, and this last curve will represent the total pressure upon the crosshead pin due to the effect of steam

and weight and inertia of the reciprocating parts. A summary of the data from which the inertia curve was deduced is given following Fig. 424, p. 987.

Thus far we have dealt with pressures referred to different

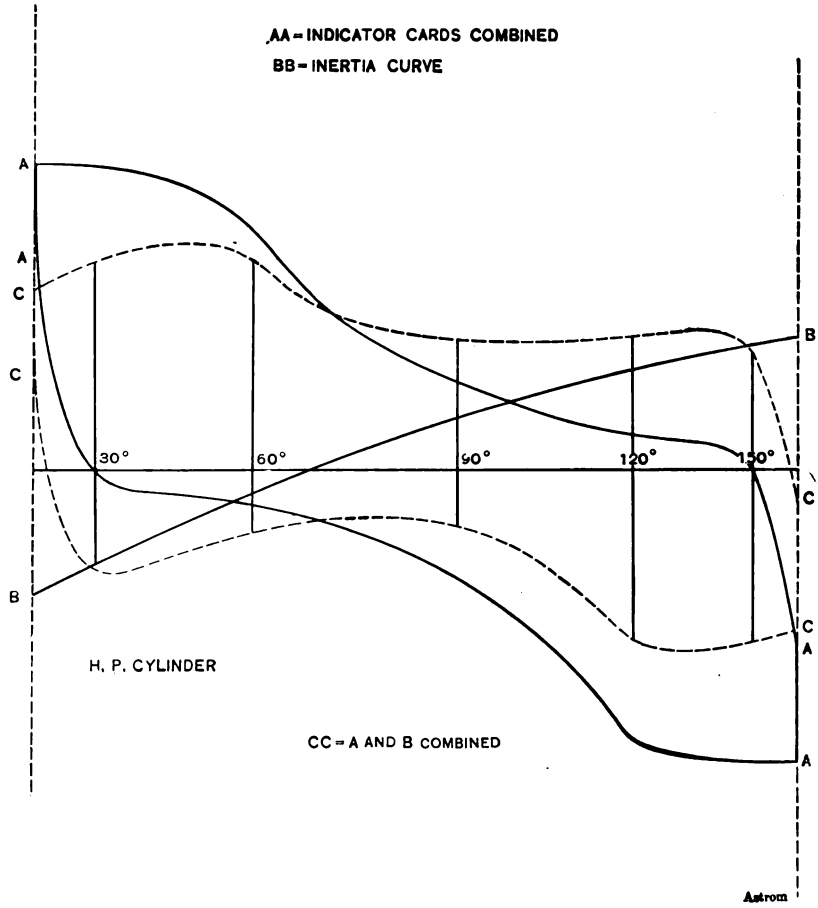


FIG. 427.

points of the piston travel. We will now c
of these different pressures at corresponding poi
pin circle.

Extend the base-line of these curves a c
length of the connecting rod, and upon it
semicircle, not shown in the cut, repre

travel; the centre of this semicircle being the length of the connecting rod distant from the middle of the line representing the piston travel. Divide this semicircle into six equal parts of 30 degrees each, and from these points of division as centres, with radius equal to the length of the connecting rod, describe arcs intersecting the base-line representing the piston travel. From these points of intersection erect ordinates perpendicular

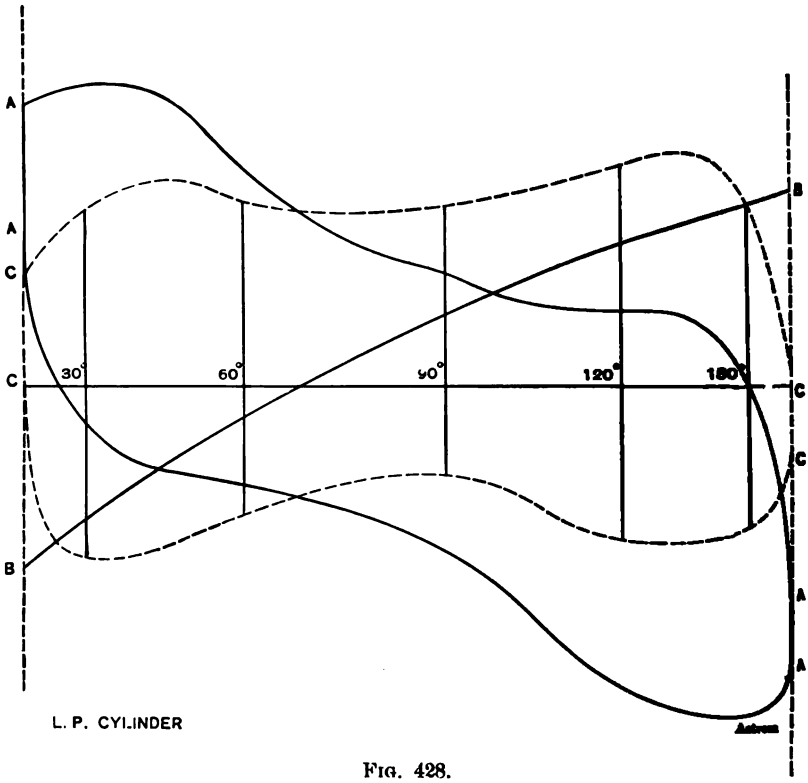


FIG. 428.

to the base-line, and where they intersect the curve *C* above and below the base-line will be twelve points, referred to piston travel, corresponding to twelve equidistant points in the crank-pin circle, for which we will compute the corresponding tangential pressures by the following method:

Referring now to Fig. 429, upon the l··· li ne *AB* strike a circle with a radius of unity; divide the circu erence of this circle into twelve parts of 30 degrees each; tht the points of

division draw lines of the length of the connecting rod terminating at the line AB. Produce these lines, if necessary, until they intersect the vertical line OC at the points e, e', etc. The distances Oe, Oe', etc., measured on the scale of which the radius OC is unity, represent the factors by which the pressures shown

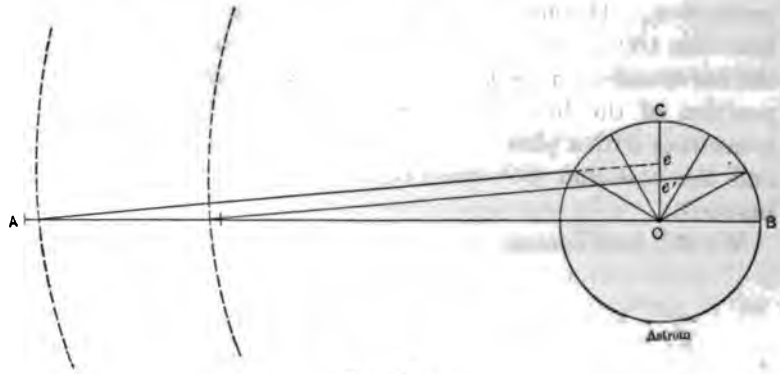


FIG. 429.

on the corresponding points of the curve C, Fig. 427, should be multiplied in order to find the corresponding tangential pressures upon the crank pin. Determine in the same way the pressures corresponding to the twelve points selected, and, upon the base-line DD, Fig. 430, representing to some convenient scale the crank-pin circle rectified, construct the curve as shown, the

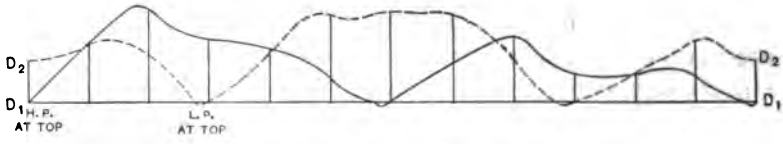


FIG. 430.

ordinates of which curve will represent the total rotative pressures for the upward and downward strokes. Determine by the same process the tangential pressure upon the crank pin of the low-pressure cylinder, as shown in Figs. 426 and 428, and construct this curve upon the same base-line, having corresponding

points at a distance ahead of or behind the curve, for the high-pressure cylinder depending upon the angle at which the cranks are set relatively to each other. This curve for the low-pressure cylinder is shown in Fig. 430 by the dotted line. The combined effect of these two curves is shown in Fig. 431, which represents the total crank effort for both cranks at all points during the revolution. Through this curve draw a line *MM* parallel to the base-line *OO*, in such a position that the areas included between the curve and the line *MM* shall be equal above and below. The position of the line *MM* may be conveniently determined by measuring with a planimeter the area included between the curve and the base-line *OO*, and dividing same by the length of the line *OO*.

We will now consider the equivalent mass of the rotating parts

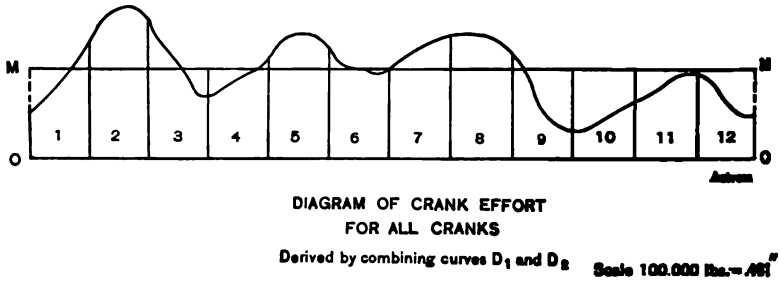


FIG. 431.

of the engine concentrated at the centre of the crank pin, and as having no other velocity than that produced by the positive and negative forces represented by those portions of the curve of crank effort on either side of the line *MM*. For convenience in estimating we will assume that the applied force is uniform within each of the twelve spaces; *i.e.*, this tangential force for each space, expressed in pounds above or below the normal *MM*, is equal to the mean height of each space above or below the line *MM*, and is exhibited in column *F* of Table IV.

The velocity gained or lost during each twelfth of a revolution is deduced as follows:

The equivalent weight of the revolving parts at crank radius (2.5 feet) equals 3,367,000 pounds. The velocity of the crank pin is $\frac{2.5 \times 2 \times 3.1416 \times 75}{60} = 19.63$ feet per second. As the

number of revolutions per second $\left(\frac{75}{\quad} = 1.25\right)$, the number of spaces traversed per second equals 15, [illegible] space, .0667 second. The mass of the [illegible]

$$\frac{W}{g} = \frac{3{,}367{,}600}{32.2} = 104{,}584. \quad \text{Hence } \frac{T}{M} = \frac{.0}{10} = .0$$

equals acceleration for a force of one pound. Therefore T equals the velocity gained or lost during each interval, in column A, Table IV.

Now, if the velocity of the pin be assumed normal at the beginning of the stroke, the velocity attained up to the end of the various spaces will be equal to the algebraic sum of the velocities gained during each of the preceding spaces. These velocities attained up to the end of each space are shown in column V''. As the actual velocity of the crank pin at the beginning of the stroke was not normal as assumed, it becomes necessary to correct the values of V'' accordingly. The integrated sum of the velocities above and below normal attained during one revolution must be zero, therefore the correction to be applied equals the algebraic sum of the velocities V'' divided by the number of

TABLE IV.

Space No.	F Tangential force in pounds above or below average pressure. F = mean height of each space.	A Velocity gained during each $\frac{1}{15}$ of a revolution. $A = \frac{.M}{}\times F$.	V'' Velocity attained up to the end of divisions, assuming 0 at beginning of stroke.	V' V'' corrected to bring 0 to its proper place. $V' = V'' - .093$.	V Average velocity during each interval.	S'' Space actually passed over during each interval.	S' Displacement, assuming 0 at the beginning of stroke.	S S' corrected to bring 0 to its proper place. $S = S' + .0018$.	Degrees of Arc. $S \times 22.92$. 1 foot = 22.92 degrees.	Degrees of Phase. There are 40 poles on the generator, consequently there are 20 changes of phase.
1	−13,500	−.0086	−.0086	−.0416	−.0375	−.0025	−.00250	−.00060	−	−
2	+57,000	+.0363	+.0277	−.0053	−.0261	−.00174	−.00424	−.00234	−	−
3	+ 4,500	+.0029	+.0306	−.0024	−.0012	−.00008	−.00432	−.00242	−	−
4	−10,500	−.0067	+.0239	−.0091	−.0072	−.00048	−.00480	−.00290	−	−
5	+30,000	+.0191	+.0430	+.0100	−.0015	−.00010	−.00490	−.00300	−	−
6	+ 1,500	+.0009	+.0439	+.0109	+.0133	+.00089	−.00401	−.00211	−	−
7	+21,000	+.0134	+.0573	+.0243	+.0155	+.00103	−.00298	−.00108	−	−
8	+30,000	+.0191	+.0764	+.0434	+.0334	+.00223	−.00075	+.00115	+	+
9	−30,000	−.0191	+.0573	+.0243	+.0390	+.00260	+.00185	+.00375	+	+
10	− 48,000	−.0306	+.0267	−.0063	+.0059	+.00039	+.00224	+.00414	+	+
11	−13,500	−.0086	+.0181	−.0149	−.0097	−.00065	+.00159	+.00349	+	+
12	−28,500	−.0181	−.0000	−.0330	−.0234	−.00156	+.00003	+.00193	+	+

spaces (twelve in this case). Thus the correction is .033, and this amount must be deducted from the values of V'' in order to arrive at the true velocity attained up to the end of the successive intervals. With these true velocities, given in column V, Table IV., as ordinates, plot the curve of velocity V', Fig. 433, where BB represents the mean velocity of the pin.

From the curve of velocity V', Fig. 433, ascertain the average velocity above or below the mean velocity, BB, during each

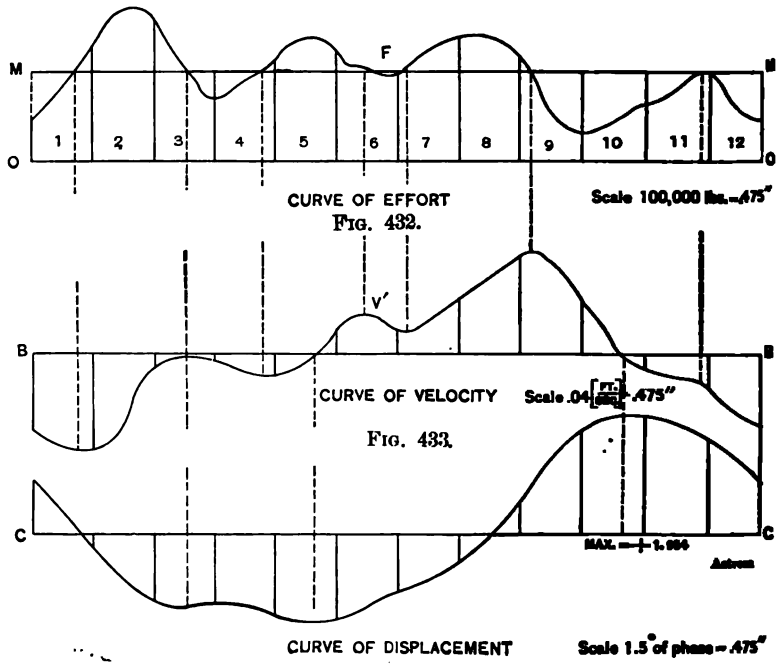


FIG. 432.

FIG. 433.

FIG. 434.

space, shown in column V, Table IV. With these velocities given, the space actually passed over during each interval can be readily calculated by multiplying the values of V by .0667, the time for one space. The figures in column S'' were deduced in this way.

If the position of the pin be assumed normal at the beginning of the stroke, its distance from normal up to the end of the respective intervals will be equal to the algebraic sum of the spaces actually passed over, ahead of or behind the mean position, during each interval. Therefore, the figures in column S' are equal to the integrated sum of the preceding figures in col-

umn S''. As the position of the crank-pin at the beginning of the stroke was not zero, as assumed, a correction must be applied to the values of S'. Since the integrated sum of the distances ahead of or behind the mean position must be equal to zero, the value of the correction is equal to the ratio of the algebraic sum of the values of S' to the number of spaces. The value of the correction is .00182, and is to be added to the values of S' to get the true displacement or distance from normal of the pin at the end of each interval, the figures for same being shown in column S. Since one foot corresponds to 22.92 degrees of arc, measured on the crank-pin circle, the number of degrees of arc from normal equals the product of the true distances in feet from normal (column S) by 22.92. The number of degrees of arc from normal deduced in this way are shown in the penultimate column of Table IV. Finally, as there are 40 poles on the generator, there will be 20 cycles or changes of phase per revolution, therefore one degree of arc equals 20 degrees of phase, and the displacement (shown in the last column of Table IV.) at the end of each interval may be calculated by multiplying the corresponding degrees of arc by 20. With the values of the displacement in degrees of phase from normal as ordinates, the curve of displacement, Fig. 434, was plotted, in which CC represents the mean position of the crank pin.

To insure the satisfactory operation of two alternating current generators when working in parallel, the maximum amount of angular variation or displacement should not be allowed to exceed $2\frac{1}{2}$ degrees of phase departure from the mean position during any revolution, and as the maximum displacement shown by this final curve is well within the $2\frac{1}{2}$ degrees limit, the design of the unit in that respect may be considered satisfactory.

Prof. P. M. Chamberlain.—During the past year two of my students, Messrs. Ludlow and Gilmore, have been working on a design of a high-speed engine for a specific purpose. The degree of steadiness required for the work was uncertain, and it was decided to make a test of an engine which was known to be giving very good service in similar work and determine that factor. They used the band wheel of the engine as a chronograph cylinder, covering it with whitewash. The first intention was to use a tuning fork to give a marking on this band wheel, but that was abandoned, as a tuning fork sufficiently large to give a measurable mark would not vibrate at a sufficiently high

rate of speed. Then the device shown in Fig. 435 was adopted. On one end of a plank is a motor belted to a spindle carrying at its end a little spring which is eccentric with the centre. If the band wheel was standing still the marking point obviously would make a small circle on the whitewashed surface. As the wheel moves, the point makes a series of loops, and the faster it moves the greater will be the distance from loop to loop. The plank is moved along gradually, so that a series of records is obtained across the face of the wheel. They used the well-known method given in that classic work on the steam engine by Arthur Rigg for calculating the factor of steadiness.

The calculated results—all the weights of the moving parts of the engine, the cards, etc.—being at their command, checked remarkably close to the experimental results. The factor of steadiness in this particular case was 150; that is to say, its reciprocal was the variation in velocity divided by the average velocity. The revolutions of the marker were very high—I think something like 30,000. The points were about 3 inches apart, and on a 4-foot wheel the variation in distances from point to point amounted to about $\frac{1}{50}$ of an inch.

Mr. Abbott.—Do I understand that the difference in the variation of speed was about $\frac{1}{150}$ of the average?

Professor Chamberlain.—Yes, sir.

Mr. Abbott.—In the case of the engine which I discussed, the variation, I believe, was about 1 in 3,000.

Prof. C. V. Kerr.—I would like to ask Mr. Abbott (1) if there is any great change in the variation of speed of the engine during the stroke between full and light loads; and (2) can the speed regulation of an engine be predicated with satisfactory accuracy at the time of its design?

Mr. Abbott.—It is my observation from some other calculations that I have made in this same matter that the load does not have a very great effect upon the variation of speed; it does have some, but not so much as one would expect. I think it could be determined beforehand readily enough what the variation would be. In fact, those curves are calculations on an engine which is not yet built.

Prof. Dugald C. Jackson.—This discussion has interested me very much, as I have done more or less speculating with respect to the effect of engines upon the working of al[illegible]tors. There is comparatively little—in fact, one may say [illegible] is nothing of

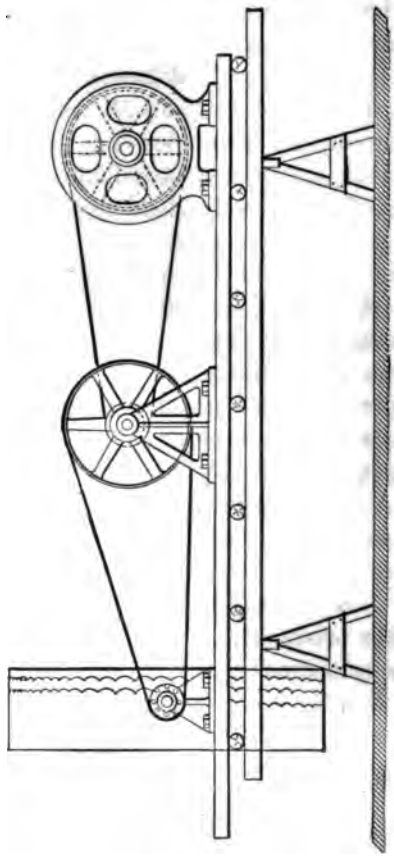
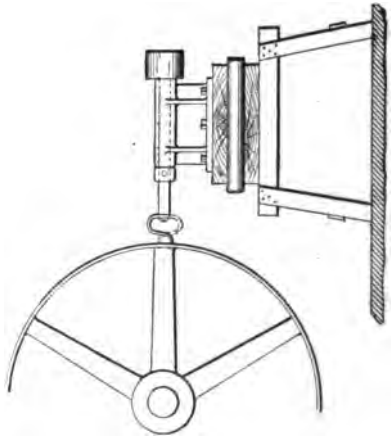


FIG. 435.



any account—in the literature of the subject that is really satisfactory in its treatment, and I find that the paper, so far as I went through it, gave me no additional light. I have never gone through the matter so fully as Mr. Abbott has evidently done; but, following up the same idea that he has carried out, it was clear to me that a perfectly satisfactory predetermination can be made of the size of the flywheel required to produce any desired degree of uniformity in velocity for any known condition of driving power. It would be advantageous if Mr. Abbott would expand his method of computation for the *Transactions*, and, if possible, make tests upon his particular engines with their generators and report the results.

I have also followed up the means for getting continuous records of the instantaneous velocities of engine-driven alternators, and I find that there is no really satisfactory method which has been developed. Various schemes have been in use; for instance, the scheme of making a lot of photographs of the flywheels, taken one after another at very short equal intervals of time, and then passing them through a kinetoscope, and watching the phantom wheel thus produced. This gives a picture of the moving wheel with its velocity reduced in any desired ratio, so that one can get an idea of its relative velocity at each instant while looking at the picture, but it does not allow of measuring the results. I doubt the reliability of Professor Chamberlain's method if it is desired to record results with a fair degree of accuracy, or to observe a very small variation of speed. This is possibly due to the fact that he drives his indicating device by means of the belt. The very slightest shaking of that belt will, in some cases, make a sufficient difference in the speed of his pointer or indicator to vitiate the result. Perhaps this would not be evident in the case of the engine which he tested, where there was a comparatively wide variation of velocity during the revolution; but in the case of some of the engines which it is necessary to use for the driving of alternators, the variation is so small that the results given by his method would probably be so inaccurate as to be entirely valueless.

Professor Chamberlain.—I would say that it is interesting to note that the consecutive records obtained side by side give a fairly good degree of certainty that the conditions did not change. If the voltage changed that ran the motor, or if there was a slip in the belt, which is scarcely likely to occur in run-

ning so light a load, it would be observable in repeated records side by side on the wheel; and in as large circumferences as would be obtained in the class of machinery of which Professor Jackson speaks, the results would be even more accurate than on a small wheel.

Mr. Reist.—This is a very interesting and important subject, and one which has received a great deal of attention in the last few years. It seems to me that it is very doubtful whether by means of any mechanical device it will be possible to measure the fluctuation of the flywheel, because the amounts to be measured are so very small. One method which has been proposed is an electrical method, and, it seems to me, has more promise than any mechanical method. I am not certain whether it has been tried or not. The plan is to build a small dynamo, to be placed directly on the engine shaft, or it may possibly be driven by a smoothly running belt, or by friction from a true pulley or flywheel, the idea being to drive a direct-current dynamo which is separately excited, and which would have a great many commutator segments to give a very even potential if driven at a uniform speed. The voltage of this dynamo is to be balanced against that of a storage battery, so that, if the speed is uniform, the volt meter will measure zero. If the speed is higher at any point, the volt meter will measure the increase of potential and therefore the increase of speed. If the speed is lower, the volt meter will again measure the difference; the idea of the storage battery being to enable one to read on the volt meter simply the differences in speed rather than to get a value representing the ultimate speed.

Mr. A. K. Mansfield.—It appears to me that there is a point of view in regard to this subject which has not been touched upon by any of the speakers, and which is the practical one. Possibly the speakers might criticise me by calling it the intensely practical one. In the first place, what is the object of determining this angular variation of a flywheel? I may be displaying my ignorance in asking the question. Behind all this there is the practical requirement of the flywheel—it has to do something. Can you tell by your apparatus whether it is doing that thing or not? If it is not, why not make it heavier until it does? That is the way we treat this subject in all other lines of engine work—we make the flywheel heavier. We have simple, well-known formulæ for determining the weight of

flywheels to suit different conditions. The constants of these formulæ are derived from experience, and what we now seem to require is suitable constants to apply in the case of this new condition; namely, alternating generators running in parallel. The analysis of the paper is, I apprehend, a very useful training of the mind—to lay a picture before one of what the flywheel has to do. I have been through such matters, though not as elaborately as is here done—this is a very beautiful analysis—but having gone to the end of it, after having read the last page, the problem still remains: *How heavy* shall we make the flywheel? We are obliged in all other lines of work to determine this by experiment. I do not know just what the form of the experiment would have to be in this line of dealing with alternating current, but I believe that there are electrical instruments —I am not certain about this—that determine whether the fly wheel is doing what appears to be required of it; and if it is, then the flywheel is found to be satisfactory. If it is not, then let us make it heavier—and, by the way, make it still a little heavier. That is the way we arrive at the result in rolling mill and other work, and I want to inquire whether that method might not be followed here.

Mr. Abbott.—I hope I may be excused for speaking too often, but I would like to call the attention of the gentleman to the fact that it would be very embarrassing, after he had a 3,000 or 5,000 horse-power engine all set up, to make the discovery that the flywheel was not heavy enough, and I think it is worth a little calculation beforehand to determine how heavy it should be. The allowable variation in speed is furnished by the maker of the electrical apparatus, who says the speed must not vary more than so much from the mean, and it is necessary to furnish a flywheel which will hold the engine within these limits.

No. 908.*

REQUIREMENTS OF ELECTRICITY IN MANUFACTURING WORK.

BY WM. S. ALDRICH, CHAMPAIGN, ILL.
(Member of the Society.)

THIS paper briefly considers some essential features of electric power transmission in manufacturing work. † Earlier treatment of the subject has been varied and somewhat scattered, but not necessarily inadequate as far as the science had been developed

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* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† For previous discussions on this topic consult *Transactions*, as follows:

No. 174, vol. vi., p. 461 : "Frictional Resistance of Engine and Shafting in Mills." J. T. Henthorn.

No. 191, vol. vii., p. 138 : "Frictional Resistance of Shafting in Engineering Establishments." S. Webber.

No. 354, vol. x., p. 823 : "Electric Motors for Shops."

No. 472, vol. xiii., p. 157 : "Electric Power Distribution." H. C. Spaulding.

No. 712, vol. xviii., p. 228: "Friction Horse-power in Factories." C. H. Benjamin.

No. 738, vol. xviii., p. 861: "Electricity *vs.* Shafting in the Machine Shop." C. H. Benjamin.

No. 746, vol. xviii., p. 1047: "Electrical Power Equipment for General Factory Purposes." D. C. Jackson.

No. 770, vol. xix., p. 467 : "Electricity in Cotton Mills." W. B. Smith-Whaley.

No. 806, vol. xx., p. 435: "On How Small a Tool Does it Pay to Put an Individual Electric Motor?"

No. 859, vol. xxi., p. 912 : "Systems and Efficiency of Electric Transmission in Factories and Mills." W. S. Aldrich.

No. 882, vol. xxii., p. 366 : "Power and Light for the Machine Shop and Foundry." F. R. Jones.

Special treatment outside of the Society *Transactions* will also be found in :

"Western Society of Engineers," Chicago, vol. i., p. 807 ; vol. iii., p. 994, *Transactions*.

"American Institute Electrical Engineers," 1899, vol. xvi., p. 145, *Transactions*.

"Institution of Electrical Engineers," London, *Journal*, July, 1900 ; vol. xxix., p. 889, *Transactions*.

"American Railway Master Mechanics' Association, Report by Committee," *Railway Master Mechanic*, June-July, 1900 ; *Engineering News*, vol. xliv., p. 18, July 12, 1900.

"Franklin Institute, Philadelphia," *Journal*, January, 1901, vol. cli., p. 1.

at the time of its presentation. The statements and principles here set forth are founded upon what has been done, upon actual experience. Additional and valuable matter will, no doubt, be brought out in the discussion of this topic.

Examples illustrating one or more of the principles involved might here be cited in detail, but complete descriptions of installations and valuable results of experience are now accessible on every hand. In fact, the whole development of this field of application of electricity is quite open and above board. It is founded upon common sense and engineering practice. It has therefore at once an advantage over many earlier and some modern or wished-for developments of electricity.

The demand for increased production is extending to all lines of manufacturing industry. It is created by the keen competition of trade and the necessity of filling orders promptly. The exigencies of business, therefore, are bringing directly to the front the question of this new motive power in manufacturing.

Factories are not built in a day, but the ready extension of existing electrical supply service has increased the output from 30 to 40 per cent. per square foot of floor space. New machines and tools cannot always be obtained on telegraph order, but a resort to electric driving has increased the output of existing machines from 20 to 60 per cent. Workmen may not be had for the asking, but giving them electric-driven machines has increased the output per man from 10 to 30 per cent. All of this has been developed without any strikes or other than satisfactory regulation of wages by recognized premium and price-rate systems.

It is an axiom that the old-established concerns get the business. To-day they must guarantee delivery on time and at lower prices to keep their factories and mills in operation. Electric driving accelerates and intensifies production for the first requirement. It reduces the cost of production from 25 to 45 per cent. for the second requirement. Of two manufacturers, each using the same size and style of latest machines, with equally skilled workmen, the one adhering to belt transmission, with its limited capacity and speeds, will probably fall behind in orders. With many manufacturers it is still a question whether the electric drive costs more to install and to maintain than the belting system. This can only be ascertained for each particular case as it arises. If it should cost more, it will still

prove a profitable investment when it increases the output per day, per man, per machine, per square foot of floor space, increasing the quantity and enhancing the quality of the product while decreasing the cost.

It is no longer a question of the efficiency of electricity *vs.* shafting for power transmission. Nor is it a mere question of saving at the coal pile when only 2 or 3 per cent. of the total cost of production is to be charged to the fuel account. In many cases electricity has effected a saving during the first year that has more than paid for the change to the new system. Whether it is more or less economical than mechanical transmission depends upon circumstances. When properly installed and operated, electricity should have inherently all of the considerations in its favor.

The resulting economy of production and the ability to fill orders promptly are all in favor of the electric system. It may be compared to skilled labor—high-priced, but very desirable from the standpoint of the economics of production. Few manufacturers still hesitate to employ high-priced skilled labor. Many more cling to antiquated methods of driving modern machinery operated by most skilful workmen. To-day, therefore, this question assumes very different proportions. The discussion has been shifted to the field of manufacturing economics, involving considerations of maximum output with given equipment, floor space, and working force. It is a question of accepting and filling orders or of losing the business to those manufacturers who can take them.

The disciplinary value of electric driving cannot be ignored. The old easy-going belt system used to allow many a glance at the morning news, many a familiar chat during long and deep cuts. With the electric drive the operator finds it very convenient to be near his machine. The customary warning signals of slipping belts are no longer heard.

Satisfactory illumination should also be provided. No one will work by a smoky torch when he can have an arc or an incandescent lamp. Electric light must be supplied in these times in all shops where they make a practice of doing a day's work the year round. Only a little wiring is required, and a small amount of extra power is necessary at the generating plant to drive machines and tools by electricity. In many instances electric lighting has paved the way for electric driving.

We have all had experience in getting men to "speed up" their machines. Tradition and custom are both against the operator who does much belt shifting. In the eyes of almost all journeymen and of some piece workers it is next to treasonable to change the rate of working. Even though paid extra, to do more than a day's work in many shops is still a crime against the union or other combination interested. The workman who attempts it soon finds a job elsewhere or is promoted. The electric drive changes all of this. A press of the button, a turn of the lever, and each piece of work can be executed at maximum speeds allowed by the temper of the tool steel. It forcibly illustrates Maxim's statement that American workmen find it pays to do as much as they can.

The ever-widening applications of electricity in manufacturing work show that it has fully proven its claim to a consideration. It is thoroughly reliable. It has come to stay. It fills the exacting requirements in this new field more economically and satisfactorily than any other system of power transmission. In the common forward movement of industry electricity is still in the van. It stands ready for any emergency within its province, and so far has been equal to each new demand made upon it.

Aside, however, from all purely technical considerations of the application of electricity to manufacturing stands pre-eminently the question: does it pay? Many manufacturers have conclusively shown that the economies of production have been enhanced by their adoption of electricity; that its inherent advantages in this relation far outweigh all previously debatable questions of economy and efficiency of the electric drive compared with belting transmission, and that even if there were no saving at the coal pile it would still not pay to return to the old method and lose orders.

I.—General Considerations.

1. *Electric Transmission in Manufacturing Work is a Means to an End:* Centralized power generation for light and manufacturing purposes; subdivision of the transmission system and the motive-power equipment; execution of all classes of work, irrespective of its location; maximum efficiency of workmen, machines, and labor involved; intensified production at best speeds and at the power limit of machines with improved quality, maximum output, and reduced cost.

2. *Sanitary Considerations:* It is healthful, clean, and free from dirt, dust, and dripping oil; it affords accommodations and facilities for proper lighting and ventilation; it removes dangers from overhead machinery shafting and belts; it reduces the sick list to a minimum; it insures quietness from absence of much unnecessary noise with older systems, and develops cheerfulness among the workmen.

3. *Disciplinary Value:* It improves the *morale* and the *personnel* of workmen; it conduces to shop order and discipline, with the most economic use of the workman's time, quick handling of material, and maximum efficiency of labor.

4. *Flexibility of the System:* Accessibility of all parts, adaptability to various uses, and portability of tools are inherent advantages.

5. *Reliability of Service:* It is free from any general breakdown, localizing casualties and stopping least machinery for repairs; no accident can affect the whole plant in any case of a modern electrical installation properly designed, equipped, and operated; it is more to be depended upon than any other system.

II. Economics of Electricity in Manufacturing.

1. *Electric Power Generation:* This system admits of centralized or concentrated power generation which is required for maximum economy. Distributed power generation in small and scattered units is very wasteful.

The electric power plant may be located to best advantage for fuel and water supplies, conveying and transportation facilities. It may be isolated from other structures, so reducing fire risks and insurance rates, especially where the boiler house is in a separate building.

The electric generating sets may be subdivided into similar and independent units. These may be operated at all times under the most economic condition of normal loads. This permits manufacturing work in any branch or section of the establishment as economically under part load as under full load, on overtime and night shifts as during the day's work.

Electric light may be supplied from the power mains or from separate generators, as conditions require. In not a few cases of the introduction of electric driving the additional saving

has been more than enough to pay for all of the lighting service.

The cost of generating electric power can only be a deciding factor when the total cost of power required is large compared to the running expense. The saving in fuel depends upon the cost of fuel, the average load, the amount of shafting and belting displaced.

2. *Electric Power Transmission:* The distances are short in factory service, the electric distribution being within one building or a group of buildings. The so-called line losses are therefore usually negligible in well-designed installations. Low voltages are employed in factory transmission. From 110 to 550 volts are the accepted limits at the present time in this country, either for direct or alternating current working at constant potential or pressure. The economics of the various systems can be only satisfactorily discussed with reference to any given project or installation.

The following are recognized methods of distribution, for electric light or power, or both, in manufacturing work:

Two-wire and three-wire systems, for direct or alternating currents.

Multi-circuit system for direct-current multi-voltage service.

Single-phase, two-wire alternating current.

Two-phase, three- or four-wire alternating current.

Three-phase, three- or four-wire alternating current.

Composite system, direct current and single-phase or two-phase alternating current on the same wires.

3. *The First Cost of Electrical Installation:* This will usually be higher for an electrical than for a mechanical transmission. The interest on first cost will rarely be a determining factor. It will be more than offset by the manufacturing economies elsewhere effected and by the reduced cost of shop buildings incident to the use of the electric drive.

4. *Maintenance of Electric System:* The cost of maintenance is a minimum. The depreciation is less than in any other system.

The saving effected is much more than sufficient to pay for all of the incidental repairs and renewals to the electrical machinery or the wiring system.

Attendance and supervision are largely centralised and reduced to a minimum compatible with efficient service, owing to the reliability of the system.

Electric generators and motors are the simplest types of motive-power machinery that can be used in the development of power transmission for manufacturing work. They have the fewest parts requiring any renewals. They require practically no repairs.

Electric machines will either work or not work. They soon make their wants known. They cannot be maintained in wasteful operation, as is the case with every other kind of motive-power machinery. Standardization of this class of electrical machinery has facilitated repairs. They are quickly and easily made, at minimum cost and with least interference with the routine work of the establishment. Small electric motors in general require more frequent attention and renewals than larger machines.

Belt tightening or lacing in the old system stops work on that section, and stops all work if it chances to be the main driving belt. Any similar casualty in the electric system is remedied at once by throwing into service another line, or a jumper, or a relay bus-bar.

III. Influence of Electric Transmission upon Factory Buildings.

The design, plan, and arrangement of manufacturing establishments are not now dictated or controlled by the new electric transmission, as always has been the case with the old mechanical system. Factory and mill construction is undergoing radical changes incident to the electric transmission of power. There is now a superior adaptation of the building to manufacturing work and sanitary requirements, with higher ceilings for light, ventilation, and overhead transportation. The cost of buildings is reduced to a minimum. The electric drive does not require the heavy construction of walls, overhead work, and roof trusses demanded by shafting transmission.

The site for buildings may be chosen independent of power considerations and located on most suitable ground. There is no necessity for buildings being placed around or adjacent to the power-house, as required for mechanical connections to engines or turbines. Grouped shops may be arranged in best manner to facilitate economic production and the handling, conveying, and transportation of material and work. Detached buildings—a tendency of certain lines of modern manufacturing

development—are feasible, and the work therein facilitated by electric transmission. The isolation of various shops, departments, and workrooms for manufacturing or insurance reasons may be carried to any extent with the electric system without impairing its efficiency or economy. The output per square foot of floor space is a maximum with electric transmission.

IV. Influence of Electric Transmission upon Workshop Expansion.

Future areas of work may be planned and arranged for with the utmost freedom and entirely irrespective of power considerations. They can be located as desired, on separate floors, in various departments, or in detached buildings. Original provision for prospective development is not necessary in the electric system, but is required by shafting transmission. There is no expense for contemplated additions till they are actually installed as required.

Permanent additions to the electric generating plant and the distributing system are made with a gradual and pro rata outlay of capital, instead of in disproportionate blocks of new equipment, as required by mechanical transmission.

Extensions of electric transmission and new centres of power distribution may be established at any time and of reasonable capacity, anywhere and at any distance, at minimum cost for labor and material. There is no crowding, overloading, or interference with existing conditions, or with the daily progress of routine work. Temporary extensions, to meet sudden demands for power at any point, are quickly made by running to the desired location electric wires or cables. These are easily removed when no longer required and as readily used elsewhere for similar purposes. The shifts are made with the least expense of time and labor in handling, and with no accompanying waste of material to suit different conditions.

Auxiliary power is always at hand for emergencies and to almost any reasonable extent, on account of the reserve nature of the electric supply.

V. Influence of Electric Drive upon Arrangement of Machinery.

The floor space required per machine or tool is reduced to a minimum.

The alignment of overhead shafting is no longer necessary.

Clear overhead room is provided for handling all classes of heavy work. The crowding and complications arising from overhead shafts and belts are avoided.

Location of machines and tools may be made to suit the requirements of the work and the available floor space. The product may then be finished with least time and labor, with least handling and transportation, and in the most efficient and economic manner.

All the conditions of work and of labor may be arranged to handle tools and material to the best advantage with freedom of workman's movements and facility in executing manufacturing operations.

VI. Changing from the Old to the New System of Driving.

When alterations or additions in power transmission are required, it is the invariable practice in many modern shops to extend in the line of electric driving. This is notably the rule where electric supply is already at hand for either lighting or power service. In the rehabilitation of an old establishment some of the shafting transmission may usually be combined with the electric drive, as in the so-called group system. Much can be done to improve the power transmission if existing lines of shafting are divided into the most economic sectional lengths, determined by the speed, character of load, and kind of work. Electric motors will prove valuable adjuncts if installed to drive these sections independently. The electric drive is an economic and flexible auxiliary, supplementing the earlier and rigid mechanical power transmission. Such partial introduction of the new system, especially if an electric-lighting plant is already in service, will early develop its advantages. It will defray the cost of installation and maintenance by greater economic production.

Scrapping the old to make room for the new involves the same economic questions in the case of power transmission as in that of manufacturing machinery. Productive machinery should not in general be scrapped while there is retained the old system of belt driving, with its inherent power and speed limitations. The increased output of the old machine, electrically driven, will frequently equal that of a new machine, belt driven, and turning out the same kind of product.

VII. Application of the Electric Drive.

1. *Individual Driving without Intermediate Gearing:* The armature of the motor is mounted on the main spindle of the machine. The power is most directly applied, with ideal adaptation of tool to work.

It requires more or less special adaptation of motor to machine, with rarely any marked changes in the structural design of the latter.

2. *Individual Driving with Intermediate Gearing:* The motor is conveniently mounted on the frame of the machine and drives it through the intervention of the ordinary gearing.

It requires no special adaptation of motor to machine. Any suitable motor may be used on any machine.

3. *Advantages of the Individual Drive:* The workman has the most perfect control of all factors entering into the economics of production. There is maximum economy in the application of power.

The speed control and the output are independent of any other machine. They are no longer limited by the speed of the line shafting. Machines and tools may now be worked to the limits of their respective capacities.

The productive efficiency of the machine is increased. It may be operated at all times up to the power limit, reducing time and cost of labor for any given product.

The choice of the individual drive depends upon the power required, the size of the machine, the time it is in service, and the value of the product.

The individual motor drive is usually adopted where the machine is in use only part of the time, and in sizes as small as two or three horse-power, and requiring wide variations in speed and power for maximum output quite independent of the first cost. For large machines this method reduces the power losses to a minimum. It is particularly advantageous for shears, punches, and a class of repair-shop tools requiring power only at intervals. The constructive details and design of direct-driven machines are not usually altered to any extent; secondary speed changes are obtained by the usual change-gear and mechanism; in special cases of large tools, a range of speeds is sometimes best provided by a special variable-speed motor.

4. *Group Driving:* A few large electric motors are employed

independently, driving sections of shafting of most economical length. This method is thus adapted for driving a number of small machines, with no particular requirements in speed or in power; or for most economical manufacturing along special lines; or for driving any section on overtime or night shifts; or for independent driving of separate floors, departments, or detached buildings.

The maximum economy with the group system can only be secured when all of the machines so driven are in constant use, at best speeds for maximum output. This dictates grouping machines, as far as practicable, of the same size, style, functions, speed and power requirements, having due regard to the work to be executed. Sectionalizing the power transmission by substituting electric motors for either the main or section belts secures partial advantages of the new system side by side with the old, and is frequently resorted to in old establishments adopting new methods.

5. *Individual and Group Driving:* The most general requirements of factory transmission can all be met by an intelligent combination of these two methods of electric driving.

The first cost of installing the individual drive will generally be from 2 to 5 per cent. higher than for the best group system, when all other considerations are the same. The individual drive is more economical in the use of power than the group system, especially if in the latter only a limited number of grouped machines are in use at any one time, under average loads.

6. *Portable Tools and Appliances:* The extreme flexibility of the electric system invites the widest use of portable tools and appliances. A flexible, heavily armored cable gives any desirable radius of action, with no expense to maintain as a part of the transmission system, with no danger or difficulty in handling, and requiring least time and labor for any immediate shifting of tool or work. Least used tools need not occupy floor space when not in operation. Most favorable economic relations may, therefore, be secured in many lines of manufacturing work, especially of the heavier grades. Almost all required tools may be taken to and operated at the work in hand. Time is saved in not having to shift and adjust the work to the machine or tool. Several operations may be carried on at one time by bringing different tools to the work, each independently driven and operated.

7. *Electric Transportation and Conveying:* Electric hauling by surface or overhead systems of distribution, electric conveying and telpher systems, electric cranes, hoists, lifts, and elevators, are all well-developed fields, and present no unusual nor insurmountable difficulties when installed as a part of the regular electric system of a manufacturing establishment. Tools are taken to the work, or machines and tools are quickly served with material and work, reducing the cost of all handling to the lowest terms in a field of non-productive labor that has formerly been very expensive.

8. *Electric-driven Auxiliaries:* With an established electric supply service for all manufacturing work it is an economic step to drive by electricity all auxiliaries, as pumps, fans, blowers, air compressors, etc.

VIII. Selection of Equipment.

1. *Factors Determining Choice of the Electric System:* Each manufacturing industry has its own inherent requirements. No general rules can be given, but every case must of necessity be studied and developed by itself with a thorough preliminary survey of all conditions and requirements. One successful system cannot furnish precedent for another.

In general, the following lines of inquiry should be freely investigated before choosing any system for power transmission in manufacturing work: the size of the establishment; the area to be served; the arrangement and grouping of shops, departments, or buildings; the arrangement, types, and sizes of machines or tools to be driven; the variety of speeds required; the character of the loads involved; the kind of work to be executed; the economics of fuel and water supplies.

The above items should have been predetermined from the standpoint of most economic production. They should in no wise be influenced by questions of power transmission. How to drive the machinery in a new and modern manufacturing plant should be a second and not a first consideration. It should be determined by, rather than itself determine, the conditions for economic production.

2. *Interchangeability Throughout the Electric System:* It should be possible to drive similar apparatus and motors from any point of attachment to the wiring system. Greater flexibility is thereby secured, added facilities provided for use of portable

tools, and readiest extension made of plant and distributing system at any time. Preferably have one, and only one, electric system if it can be secured by intelligent consideration of all present and the most probable future requirements. This does not necessarily imply that it is best to have one single circuit for all kinds of service required in a manufacturing establishment, as light and power; but it should not be required to use different circuits for the same service, as portable tools.

3. *Uniformity of Electrical Equipment:* Generating sets and motor equipments should be standardized as far as possible in the case of any given establishment. These machines, as well as all their parts, should be readily obtained in duplicate at any time. This is particularly important in making additions and extensions in the group system, where it may be required to change from a smaller to a larger motor at any time to accommodate more machines on a given section. It cannot be advantageous to experiment with different styles and types. Electrical machinery to-day is so far standardized, and its performance predetermined, that there can be no excuse for not selecting that style and type best adapted to any given factory.

4. *Power Required as a Basis for Size of Electric Motor:* The load diagram for any machine will furnish the best data for determining the proper size of motor. It may be readily obtained under the working conditions of the machine by using a test motor.

In almost all metal-working industries the power required is subject to extreme fluctuations, and may be very heavy, at times, while the bulk of it will be quite light. It is not necessary to install an electric motor to carry, for any length of time, such sudden and heavy loads as will be shown by the peaks of the load diagrams for the several machines, or the sudden initial throw of the ammeter needle.

The limit of overload is fixed by the allowable rise of temperature, and can readily be predetermined for any given electric motor. In general, the surface temperature of the motor field coils, as measured by a thermometer, should not exceed from 35 to 45 degrees C., with a maximum limit of 50 degrees C., after an overload run of from six to eighteen hours, as may be specified by the builders.

Starting-load currents are of course high, and may be from two to three times the normal current, as in the case of over-

loads, for brief periods. Individual drives require proportionately larger motors to enable them to carry alone the heavy overloads. Group drives require only normal load motors, as it will rarely ever occur that the several grouped machines are all carrying overloads at the same instant. Motors for this service may often be much smaller than would be dictated by the combined load diagram of the machines forming the given group or section. In no case will they require to approach the maximum, or the sum of the maximum, loads of the various machines. Group system load curves will be smoothed out considerably. In all electric motor installations there should be ample power provided, rather than a narrow margin only to work upon. Increasing loads are almost sure to arise in time. A motor of ample size gives that reserve power so characteristic of the electric system, if properly installed.

5. *Character of Loads in Manufacturing Work:* Load curves and diagrams of individual machines, groups, sections, and the entire plant, only can be relied upon in estimating the character of loads being carried or likely to be carried under similar conditions. The load factor—the ratio of the average to the maximum load—for any given time on any part of the system, should be as high as possible for best working efficiency and economy. It may be largely influenced by the way the operator handles his motor. Whatever the kind of load—uniform or variable, light or heavy, continuous or intermittent, suddenly fluctuating or periodically variable—it must be carefully investigated before installing electric motive power. In certain instances flywheels may be useful and for the same mechanical reasons as elsewhere employed in machinery.

6. *Speeds of Manufacturing Machinery:* The speeds should be predetermined by the conditions for most economic maximum output, and so fix the range required for the electric motors. In no instance should the reverse be the case. In many cases of individual drives it may be best to secure the speed reductions mechanically, as by the ordinary change-gear. It is not necessary nor advisable in all cases to secure the same by mounting the motor armature directly on the spindle of the machine. Provide motors with speeds consistent with the range of change-gear, and gear down rather than up.

7. *Electric Generators Required in Manufac* *lants:* The style and type should be largely determined by t kind of ser-

vice to be supplied, the size by the normal and overload conditions as shown by the plant-load diagrams, with due considerations given to special conditions and variable loads.

The actual normal capacity of the generator will be chiefly determined by the length of time the various motors are in use, rather than by their normal or aggregate capacity. It may happen, owing to the intermittent use of machines and motors, that the generating plant may be reduced to 50 per cent., or even to 20 per cent. of the aggregate normal capacity of the motors out in the establishment. An increase of the electrical system can only be intelligently made from a careful study of the load curves of the existing installation, and using it as a basis for comparison with the probable load curve under the proposed conditions. There should be judicious subdivision of the generating plant into units, preferably of the same size and style, that they may be readily interchanged and duplicated at any time, with one or two relay units for emergencies and extra rush seasons of work. All generating units used in manufacturing installations will necessarily be of such size as to warrant their being driven by direct connection to engines or turbines. If generators required are too small to warrant direct connection, the establishment is too small to warrant an introduction of the electric drive.

8. *The Electric Wiring and Distributing System:* All wiring should be done in accordance with the "National Electric Code," being the rules and requirements of the National Board of Fire Underwriters. Separate service circuits, from the same or separate bus-bars, may be provided to advantage, for lighting and various power uses. Sub-stations, or sub-station switchboards, should be provided for separate shops, floors, departments, or buildings, making it unnecessary to run a separate set of wires back to main switchboard for each service.

9. *Indirect Electric Distribution:* Indirect distribution, through the use of accumulators, converters, or transformers may be found expedient under certain conditions. For the three-wire systems, some type of accumulator or motor-generator balancing set is almost essential for efficient regulation. The accumulator may render as invaluable service in certain kinds of factory installations, as in iron and steel mills, as it is now rendering traction work, where the character of the load variations of the former is somewhat analogous to that of the latter. The

loss in the battery is very small and entirely negligible compared to the advantages to be derived from its use in manufacturing plants of the type mentioned.

IX. Losses in Factory Transmission.

The inherent losses common to all systems of factory transmission are due to the intermittent and irregular use of the machines driven. These are reduced to a minimum with the electric drive. There is no consumption of power when the motor and machine are not in operation. There are no power losses when the motor is not in use, no so-called dead load losses, due to mechanical friction of the shafting system, no transmission losses in the line when the electric current is not required.

Electric generators and motors, when in operation at uniform speeds, have, generally speaking, but two kinds of losses: the first is a constant quantity depending upon the size and type of machine; the second is a variable loss proportional to the square of the current in the armature circuit. The electric line and other wiring has a loss proportional to the square of the current carried. The cost of waste power in the mechanical system becomes excessive at light and frictional loads. It is saved in the electric system, in which the constant losses are minimized and the variable losses are throughout proportional to the amount of work being done.

X. Efficiency of Electric Transmission.

The efficiency of the electric system under normal conditions shows high maintained values, from about 25 to 35 per cent. underload to the same amount of overload, for the individual generators and motors, as well as for the aggregate efficiency of the installation. In mechanical transmission there is a constant falling off in efficiency at various underloads in every part of the system, owing to the inherent losses due to mechanical friction, which losses are constant at all loads and constant speeds. It is not a question so much of the individual efficiencies, in either case, as of the aggregate or combined efficiency from engine or turbine shaft to machine or tool. The perform-

ance should be considered and compared at proportional parts of the full load as well as at normal loads. The mechanical efficiency of all manufacturing machines is almost invariably low. It is possible materially to effect it by efficient motors properly selected, installed, and operated.

The all-day efficiency may be made higher with the electric drive than with any other system, as the amount of time is minimized during which machines and tools are necessarily idle.

XI. Operation and Testing of Factory Installations.

1. *The Generating Plant:* As far as practicable, each unit should be operated at its normal capacity—additional units to be switched in as may be required by the manufacturing conditions.

2. *The Motors:* Rarely the case that any machine or tool is started from rest with full load upon it. Motors may be started best under the usual friction, or light loads on the machines, as in the belt systems. When the machine is brought up to proper speed, work may be thrown on to it. In this respect the practical operation of an individual electric drive follows closely that of the belt system.

It is always possible to tell exactly what is going on in an electric drive, both in kind and amount of useful work, as well as in matter of wastes and losses. Power measurements are made at any point by ammeter and voltmeter, or by a wattmeter alone. A special test motor of known performance lends itself admirably to comparative tests of the performance of machines and tools under various conditions. Workmen may know at any moment whether they are driving tools or machine to best advantage for maximum output at best speeds.

The definite power required for definite work may be determined and charged to each machine, tool, or piece of work, and so make up the shop cost of production more exactly than by any other system. The power lost in friction of individual machines when running empty may be obtained with equal facility and compared with that required in doing useful work. It will be found that the latter increases almost directly as the resistance being overcome by the machine in its operation under working conditions. The power required by the work is a small per cent. of the total power delivered to the machine.

DISCUSSION.*

Mr. J. D. Riggs.—Electric transmission is certainly desirable for many machines about a large factory, but for those machines requiring constant speed and located within reach of the engine-room, it seems to me that there is little or nothing to offset the 30 per cent. lost in transformation of power and the increased cost of plant. I see no economy in driving a line shaft by belt from a motor when the same belt will reach the engine.

Why not use belt transmission along with electric?

If there is but one engine the belt does not necessarily need to come off before the generator can be direct-connected.

Prof. C. H. Benjamin.—I regard this paper as an excellent summary of what is known to date concerning the economic reasons for using electric power in shops, and the best methods of installing.

I am glad that the author emphasizes the fact that mere economy of transmission is one of the least of the reasons for using electricity. In most manufacturing establishments the cost of power is so small compared with the cost of labor that power economies are of relatively small importance.

It is true that much power is unnecessarily wasted by shafting and belts, as was shown by the experiments described in the *Transactions* (vol. xviii.), in a paper on friction horse-power of factories. These experiments showed that of the power developed at the engine less than half usually reached the machine; furthermore, that such friction loss was unnecessary, and could be reduced from over 50 to less than 20 per cent. by proper care in erection and maintenance.

On the whole, electricity has not so far made a much better showing. Experiments on heavy machine tools at the Baldwin Locomotive Works, driven by individual motors, show a loss of power of over 15 per cent. due to motor and counter shaft alone. Sixteen different machines gave an average total horse-power of [illegible], an average consumption by motor and shaft of 2.35. [illegible] under the most favorable circumstances, heavy loads and [illegible]

[illegible] driving is resorted to, the

* [illegible] to a paper by Mr. John Eld[illegible] Tools," which will be found [illegible] xviii.

losses are necessarily larger. An article by the writer in *Cassier's Magazine* for January, 1900, gives a summary of four tests on group drives where the motor and shafting losses range from 26 to 44 per cent. of the total power used.

During the past year tests made in four manufacturing establishments in Cleveland show a loss in motors and shafting of from 38 to 58 per cent. of the total power received.

Thus we see that under practical conditions electrical transmission does not show much reduction in friction losses as compared with belts and shafting.

Electricity is being used wholly or in part by at least ten different establishments in Cleveland, as a means of transmitting power. Five of these have been equipped within the last two years.

Electrical transmission is gaining ground, not because of a saving in friction losses, but because it permits a better arrangement of buildings and machines, and facilitates the rapid handling and machining of work. In other words, as the author of the paper says, it increases the output per man and per machine.

Saving on the pay-roll and on the interest account is of greater moment than fuel economies.

The use of direct or alternating current, of individual motors or group systems depends on local conditions. For isolated, heavy machinery requiring at least 5 horse-power per unit, direct current individual motors seem to be generally preferred.

In such cases speed control is usually effected by an intermediate shaft, but in some instances a rheostat is used.

Where the machines are smaller and are arranged in groups driven by short-line shafts, induction motors are the favorites, preferably hung from the ceiling, and requiring no more attention than countershafts. The group system is particularly advantageous where a large number of machines of the same general character and running at a constant speed are employed, as is often the case with turret lathes and screw machines.

I have collected some data with regard to the actual shop efficiencies of motors, direct and alternating, group and individual, as used in Cleveland, and hope at some future time to present them to the Society.

Prof. Dugald C. Jackson.—The Secretary was kind enough to request me by letter to prepare a discussion of Professor Aldrich's paper. I have done this, but prefer to make it a dis-

cussion of the two papers of Messrs. Riddell and Aldrich, taken jointly.

So far as the use of electricity for power distribution in manufacturing establishments of reasonably large size is concerned, it requires no general brief to be submitted; but it requires such papers as Mr. Riddell's only to make it more general. This adoption has gone so far that a general brief such as Mr. Aldrich thinks necessary needs in reality no longer to be prepared. There are a great many special details, however, which do require attention, because full attention has not yet been called to them. I had intended to speak myself on the questions particularly relating to speed control over wide ranges of speed, but the Secretary was kind enough to say in his letter that he would be glad to have some one of our people who is expert on the subject of these papers present a written discussion, if I could not find it convenient to do so. One of my assistants, Mr. Frankenfield, has given a great deal of attention to this question, and, as I have been very busy, he has been kind enough to write out for me some discussion which I will read.

"The average engineer is so thoroughly steeped in the old ideas regarding the distribution of power in manufacturing establishments, that, in considering the electrical equipment of factories, he is liable to give the question of coal-pile altogether too prominent a position. The fact is that calculation for a particular case seldom shows enough saving in coal by the electrical drive to pay interest on the increased investment. Most manufacturers have, from time to time, considered electrical equipment, and many have dropped the subject at precisely this point. The result has been an enormous inertia, politely termed conservatism, which has not yet been altogether overcome.

"There are so many real advantages in the electrical drive that it would, in fact, pay to install it even with an increase in the coal bill. Having decided to electrically equip, it is then well enough to consider the fuel account, the criterion being the greatest production with the highest energy efficiency. Confining the present discussion to but one of the advantages, increased production (per man, per machine, per unit of floor space), let us consider how this may be derived most fully.

"There are two methods of electrical equipment, the group system and the individual drive. The group system is at present the more prevalent. This is due in large measure to the fact

that no special designing of driven machines or driving motors is required. We may expect this system to prevail in new installations for a few years to come. It has many advantages over the old shaft and belt system, but its chief advantage lies in the economies incident to the obliteration of the so-called main shaft. In many shops this is not as yet made the most of. It is a common thing to find, for instance, all planers grouped on one motor, all milling machines on another, and so on. The result is that during periods of financial depression a number of motors are operating at light load and low efficiency. From the standpoint of power economy, machines should be grouped so that the motors are always kept well loaded. In a large machine shop, for instance, it is well to have one motor driving one group of planers, another motor another group of planers, and so on; but in a small shop it is far more economical to place a planer, a milling machine, a screw machine, and one or two lathes in one group, and to arrange similar groups so that a portion of the motors may be shut down during strikes or periods of financial depression. None of the economies resulting from facility in changing speeds are available with this system. Machines, however, requiring small speed variation and but little individual power may be economically operated on the group system; but if the power per machine is large, the direct drive should be considered before making a final decision.

"Passing at once to the question of individual drive, we are confronted with what was at one time a knotty problem for the electrical engineer. The large turret lathe may be taken as a typical machine, and also *the* typical machine tool for this class of drive, since its requirements are most rigid.

"These requirements are:

"1. A wide range of speed, with small steps, and reasonably constant speed on each step.

"2. Economical operation at all speeds.

"3. A constant driving power throughout the range of speed; in other words, a maximum driving torque which varies inversely with the speed.

"4. The motor must be reversible and possess the usual qualities as to sparkless operation, heating, and overload capacity.

"5. It must be dust-proof.

"Alternating current motors meet the fourth and fifth requirements admirably, but in their present construction fail to meet

the first, second, and third. The direct-current motor is therefore preëminent in the field, and, as pointed out by Professor Aldrich, should be of the constant-pressure type.

"Two methods of satisfying these requirements are at present in limited use:

"1. A standard constant speed motor is connected to the lathe by means of a nest of variable ratio gears. The noise and unsightliness are enough to convince any one of how not to do it.

"2. A variable speed motor of low range is connected to the lathe through a smaller nest of gears, a good argument for dispensing with change gears entirely.

"After six years of study and no little experimentation, the writer feels warranted in predicting that all speeds will finally be obtained by motor control, even back gears being dispensed with. Any speed can by this means be quickly and instantly obtained. A single reduction gearing is permissible between motor and spindle, and this avoids a motor of excessive weight. A speed range of as high as 10 : 1 or more will be required. It will take some time to bring about standardization in this line, and a great deal of engineering inertia must be overcome.

"A series wound motor would at first thought seem to meet all requirements, but its speed regulation is fickle with changing load, and it has a pronounced tendency to race on no load.

"A cumulative compound motor obviates the latter difficulty, but requires external devices to obtain a wide range of speed control; furthermore, its speed regulation is none too good.

"So long as external devices are needed, the shunt-wound motor might as well be used, its regulation being better.

"The two common methods of controlling the speed of shunt-wound motors are:

"1. By rheostat inserted in the armature circuit.

"2. By rheostat inserted in the field circuit.

"The first is inefficient and results in abominable regulation.

"The second, while highly efficient, is limited in range on account of sparking at the higher speeds. A range as high as 3 : 1 may be obtained by expensive construction, but this is not sufficient to meet the requirements of many types of machinery, including that under special consideration.

"The multi-voltage system has been used to me extent. Here the fields of the motor are excited at one ge, and the

armature terminals are connected as desired to the various leads of a multiple-wire system, intermediate speeds being obtained by armature or field rheostat control. This does not meet the requirements as to torque, and if the motor is so designed as to do the required work at the lowest speed, it will be operating below its rated capacity at the higher speeds.

"Several generators are needed in the multi-voltage system which aggregate a larger capacity than a single generator on the two-wire system; and the average operating efficiency of the several generators is lower, the total first cost and depreciation greater, and the provision of spare units in the power plant more expensive.

"Added to this is a complicated and expensive system of wiring, difficult to keep up, and almost impracticable for use with portable tools. It is not so easy to wire for temporary installations, and requires an expert electrician to make the connections to the motors; while an ordinary workman can do this in the case of a two-wire system.

"Contradistinguished from these methods of control there are two methods which meet all requirements. In one the motor has an armature with several unequal windings, different fixed speeds being obtained by connecting these windings in various combinations, and intermediate speeds being obtained by field rheostat control. In the other, the motor is multipolar, and variations of speed are produced by varying or removing the excitation on one or more poles, or reversing the excitation on some of the poles. At least one pole is always kept at full excitation to avoid sparking. In case of reversal of the excitation of some of the poles, a preponderance of magnetic flux is maintained in one direction so as to avoid an undesired reversal of the direction of rotation of the motor. These two methods may be used in combination, or separately, or in combination with some other method, such as field rheostat control.

"I will consider these forms of motor in some detail.

"In the case of the motor with an armature which has several (two in this case) windings, we have the following conditions:

"Let a = no. conductors in long winding.

" b = " " " short "

ORDER OF STEPS.

A (when $a-b < b$).		B (when $a-b > b$)	
Step.	Connection.	Step.	Connection.
1.	$a + b$ (Conjunction)	1.	$a + b$ (Conjunction)
2.	a	2.	a
3.	b	3.	$a - b$ (Opposition)
4.	$a - b$ (Opposition)	4.	b

"For equal percentages of change in speed, combination A should have two windings arranged so that $a : b = 1.68 : 1$; each step would then be approximately 66.8 per cent. higher than the one below it. If $a : b = 5 : 3$ this condition is practically fulfilled, the successive speed ratios being 1.6, 1.66, 1.5, and the speeds, say, 100, 160, 266, 399, or approximately in these ratios.

"If in combination B, $a : b = 5 : 2$, the successive speed ratios will be 1.4, 1.66, 1.5, and the speeds, say, 100, 140, 232, 349, or about in these ratios.

"Equal increments may not always be desirable, and the windings may be arranged to suit conditions. The range may be widened by any of the combinations previously suggested.

"A peculiarity of the double armature is that when one winding is idle, the coil under commutation in that winding acts as a short-circuited secondary to the commutated coil in the active winding. Thus a large part of the self-inductive discharge due to the reversal of current in the active coil, is taken care of by the so-called idle windings, and the tendency to spark minimized. For this reason combination B (that is, where $a - b > b$) recommends itself where field rheostat control is used in obtaining the highest speeds.

"In the case of pole commutation, a wide range of speed is obtained when the motor is highly multipolar; an eight-pole machine giving a ratio of speeds of 5 : 1 and a six-pole of 3 : 1. Certain poles may be cut out gradually, the connections to those poles reversed, and the excitation applied gradually, thus giving a smooth gradation of speed. Just what the steps will be after a particular pole is cut out or reversed, depends upon the total number of poles, and on the reluctances of the magnetic circuits; in other words, the steps may be controlled by the design of the motor. The motors for this system should have two path armatures.

"The objection might be raised that commutation of poles

produces an undesirable magnetic pull. If the shaft is made heavy this is no more serious than belt pull in an ordinary belted motor. By operating on poles beneath the centre of gravity of the armature the effect is reduced.

"A combination of these two methods (plurality of armature windings and pole commutation) gives an enormous range of speed. A six-pole motor with armature windings in the ratio of 5 : 3 will give a range of 12 : 1, while all the requirements named above will be fulfilled. The electric wiring of shop circuits in operating such motors is the simplest possible, a plain two-wire system. Such a motor has been designed to give 3 horse-power at any speed between 150 and 1,800 revolutions per minute. Such an enormous range of speed meets almost any need. In point of cost, this motor must be charged with one additional commutator, about double time required in winding the armature, an extra heavy shaft and bearings, and a slightly more expensive controller than in the multi-voltage system. But these are counterbalanced against the various disadvantages and complications of the multi-voltage system.

"The efficiency curve of a machine for this class of work should be as high as possible at light load, even at some sacrifice of full load efficiency and of regulation. An investigation of the various methods for controlling motor speeds places them in the following order of merit as to efficiency:

"1. Pole commutation.

"2. Plural armature windings.

"3. Multi-voltage system.

"Any system of individual drive with wide range of speed variation requires a heavy motor. Such a system will pay whenever a convenient speed control largely increases the earning capacity of the driven machinery."

I wished to bring to your attention the question of speed control, inasmuch as the problem of variable speeds must now be dealt with, and dealt with successfully, or the convenience and satisfaction of electric drives will be very greatly limited; it will be limited to those operations where a difference of speed is not required, or can still be had by pulleys and other mechanical means, or where economy may be sacrificed to convenience, as in crane service. This method of control, which I have just described, deals with the question successfully, and it is the only method which does so.

I will now briefly return to the general question. The applicability of the electric drive is, in many respects, greater than Mr. Aldrich seems to believe; for example, he is not justified in the statement that unless the plant is large enough to demand direct-driven generating units, an electric drive should not be used. There are many plants where such a dictum would virtually rule out the electric drive, on account of the great expense of the generating unit, especially where alternating currents are desirable, though the electric drive would be in other respects of great advantage. On the other hand, the rope-driven generating unit gives entire and absolute satisfaction. There is no ground for making the limitation so marked as Professor Aldrich has done either in this or in several other cases in the paper.

Mr. R. A. Widdicombe.—The query suggests itself, as to whether or not group driving will be the final outcome of electric driving of factories, except in cases of large machine tools, requiring from, say, 2 to 3 horse-power each, and these are in the minority. I would like to ask what the speed has to do with electric driving, or rather what electric driving has to do with the speed? Has the author not mixed up the general question of shop economics with the special one of electric driving? The output is, of course, more or less dependent on the machine speed; but his deduction, that electric driving has increased the output by increasing speed, is not true. As we do not allow one, we disagree with both deductions. The examination of modern machine tools will show that they are well powered, the speed increases are well designed and easily applied.

Mr. F. V. Henshaw.—I think the last speaker has missed the point. Of course in speed alone there is nothing to gain by electric driving. The point is to be able to change the speed rapidly, to adapt the speed of the machine to the work that it is doing, and make it just as high as possible without having to change belts on cone pulleys or gears, and, after changing, to discover that the speed is too high and have to change back again. The object sought is to be able to furnish a control that will enable a workman to bring the cutting speed up without loss of time.

In regard to the systems of obtaining variable speed motors, I think the comparisons made are a little bit deceptive. In the first place, if I remember rightly, it was stated that the multi-

voltage system required a good many dynamos. As a matter of fact, it requires only one dynamo, with a balancing motor-dynamo, and the latter does not need to be very large, either, if the plant is of considerable magnitude, so that the various tools, working at different speeds, will balance up against each other. It is a conceivable condition that at times there would be no load at all on the intermediate balancing machine. The size of the balancing machine is, of course, something that would have to be carefully worked out for each individual case.

Another point is that the multi-voltage system is of great advantage in using a motor that is standard; it might be relatively large, but the motor would be absolutely standard.

The objection as to complicated wiring I think is not important. The multi-voltage wiring is really quite simple and can be handled by an ordinary wireman.

It is very difficult to generalize on the various methods of electric driving, because different establishments differ so much in the kind of work they do, the lay-out of plant, the peculiarities of tools, and the way they are worked. The only safe plan is to very carefully work out each individual case and try these various methods on it; but, in general, the saving in other respects has to be very great to overcome the objection to any electric motor which combines such special features as double or triple commutators, various combinations of poles, windings, etc.

One of the most important points in an electric-driven plant is to have one man who understands the care of the machinery and to whom it is confided. It is simply astonishing to find the small amount of knowledge and the great amount of negligence shown in many cases; the expense and loss of time thereby incurred would be entirely avoided if there was one man in a plant whose duty it was to look after such things, and I am sorry to say that in many plants there is not. Machinery will run down, and yet the average shop man thinks that electric motors must not be touched except by an electrical engineer. Why, I have known of a case where, when the oil gave out in one of the oil wells of a motor, the shaft froze, and instead of examining it to see what was the matter, they sent off 500 miles for an electrician to come and fix it. Now this is a very important point, that the man in charge of electrical machinery should be one who understands his business.

Mr. G. N. Comly.—The question of the introduction of elec

tric motors for the driving of machinery is, of course, a very extensive one, and is susceptible of a great deal of consideration.

The discussions this evening, so far as I have understood them, have referred particularly to the use of motors for driving machine tools. That is, perhaps, a part of the use of motors which can be definitely handled, more so than some others, but with a large establishment the question is not only of machine shops, but of other places as well; and it seems to me that the use of electric motors in large works, where the demands for power are scattered, is an indication of a greater value for electric driving than simply in machine shops.

In machine shops it is a question whether you put a motor on each machine or use one to drive several machines. With very large machines no doubt an individual motor to each one is the proper thing. Our electricians will, perhaps, explain to us what they can do in the way of building small machines, and at the same time making them practicable.

The question of change of speed is a very important one, and we find it important not only in machine shops, but in other places. In large works the problem is very complicated. We have found in many cases that motors have been valuable to us, not only owing to the convenience in putting them in isolated places, but also in places where it was not convenient to run steam pipes; and where the works occupy perhaps a space of half a mile long we can thoroughly appreciate that advantage.

The question of making motors that will resist the action of chemicals and of foreign substances is a matter in which some of us are interested and about which we shall be glad to have considerable explanation. Also the other question of easily changing speeds; I think that is a very important matter, and it looks as if the electricians themselves were somewhat in the dark as to what was best to do in the direction of making something that would be easily and simply changed in speed.

I feel greatly interested in this problem because we have these matters constantly coming up, and, as I say, in very peculiar situations. The motors have come to our assistance with gratifying results; and yet we cannot accept the motor problem as perhaps some others can.

The question as to what you are going to do with your steam after it passes through your engine is an important problem.

Frequently it is better to put the engine directly on to a machine and isolated from the boiler, simply because we want the heat there; and in many cases the steam is more important for heating purposes than it is for engine driving; then the engine becomes simply a reducing valve, in which case it does not pay to put in a motor.

There certainly is a broad field for the use of motors, and for one I would be very glad to have any light that our electricians can give us.

Mr. S. L. G. Knox.—I consider the point made by Mr. Henshaw about the man who handles the motor in the shop very important. On a trolley car or on a crane the operator is hired to run motors, and if he does not run them properly another man is obtained who will run them properly. But in a printing-office or a machine shop you cannot have a satisfactory operator to start and stop the tool or the press; the men are prejudiced against motors because they have always used mechanical drives, and if they are good pressmen and good machinists, that is all the shop managers want of them. Power in the average shop costs anywhere from 1 to 2 per cent., and the labor and material, of course, the rest; the manager always prefers a man who is the best machinist or printer, and he does not care what he does with motors or controllers. Therefore the system adopted is particularly important. There is one argument in favor of the standard motor that goes with the multi-circuit system, because it is an older and better established and better manufactured piece of apparatus always than a special machine, and that might outweigh quite a little complication in the controller. I cannot say that there is any more complication about it, because armature control does not bring in any more complication than the changing of fields, etc. One point, however, is that in a small plant with the multi-circuit system the balancing generator must have capacity nearly equal to the main dynamo. It is a mistake to say that it only need have part of it, because in a small circuit you are apt to have the whole load on one side at one time. In a bigger plant the capacity needed in the balancing machines decreases because the law of averages takes care of it. Those who have had experience with the installation of motors in machine shops often prefer that the men would leave them alone. So it becomes desirable in a shop where there is an electric motor installation to have a special man who does the

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whole work, for two reasons: first, that the man at the machine does not know how; and, second, he does not care.

Mr. Bolles.—In speaking of the necessity of large capacity for the multiple-voltage machine, I might cite one plant that we have installed, having a capacity of 500 kilowatts in generators, and 50 kilowatts in the multiple-voltage machine. There are 73 motors installed, with a total capacity of 822 horse-power.

Mr. F. R. Low.—I would like to ask how far that principle which consists in withdrawing part of the field is applicable to this subject? By withdrawing part of the field, the speed of the motor would be gradually decreased.

Mr. H. G. Reist.—The remarks made by the speaker in referring specially to machine tools and their work might be extended, I think, to almost every variety of work. I have in mind especially the work in cotton mills. There the engines—if the mills are engine driven—are generally so speeded as to drive the machinery to as high a limit as possible; but on damp days, when the belts slip and stretch more than usual, the machines slow up, and thus reduce the production just that amount. This shows the desirability of omitting belts as far as possible, and keeping the speed up to the maximum at all times. Also in weaving machinery, a uniform speed is very desirable, and this can be better obtained by motors than by belting.

One of the speakers asked regarding the use of motors in places where corrosive chemicals are used or where motors are exposed to dirt or grit. I might say that such difficulties are usually solved by using an enclosed motor or by the use of an induction motor. I had occasion within a few days to visit a plant which was equipped with induction motors, and which, from the nature of the work that was being done, was in an exceedingly dirty place, but it did not seem to injuriously affect the operation of the motors. At this particular place the plant was equipped with air pipes carrying compressed air for the more important motors, so that they could be cleaned readily; but even that did not seem to be necessary for motors of this class.

The author of this paper has covered the subject so thoroughly that little more can be added. I wish to express my appreciation of the paper, and I feel that the Society is to be congratulated on having two such papers—the one which the author read a year ago and this one—on this subject.

Prof. W. S. Johnson.—I would like to mention an instance

where electricity, taking the place of a belt drive, has served a purpose which cannot be served by a belt drive. Two or three years ago I placed upon a printing-press for the *Chicago News* a controller for the motor running the press. Of course you all understand that absolute uniformity of speed is a non-essential with a printing-press, but it is very important that there may be perfect control of the speed of the press, a printing-press being of such a complicated nature, and the paper being so easily torn. The pressman must be all about the press, and must be enabled to control its speed from every direction. Now a series-wound motor runs this press to which I have reference. There is placed upon the press a pneumatic control speed regulator. In fact, there are several of these stationed about at ten different places on the press, where the pressman can control the speed. He places his finger upon a button and presses it, whereupon the press starts and continues to accelerate in speed until he removes his finger, when the speed will remain constant until he manipulates the machine in some other way. He watches until he sees that everything is running right, and then goes around to the other side of the press, perhaps, where he may want to observe something, and puts his finger on another button; the press begins to slow down until he takes his finger off, when it runs at the speed he left it until he is satisfied or has observed what he wanted to. He then puts his finger on the first button, and again accelerates the speed. It does not make any difference at what part of the press he is, if he is moving about and observes that the paper is beginning to tear, or that anything is happening which is not right, he touches a third button and the press stops instantly. Now, that cannot be done with belt transmission in any possible way.

Mr. Henshaw.—It is so easily manipulated that you can do things you cannot possibly do by belt transmission. For example, in a large steel works in Pennsylvania they are cutting I-beams with a saw driven by an electric motor; the beams are put on a table and the table is driven by a small motor. In front of the operator is an ammeter in circuit with the small motor. With a saw of that kind you can put on almost an unlimited load. The operator can control that perfectly. He keeps pressing the beam up against the saw, keeping the needle of the ammeter at the top point, and he can reverse and pull it back at any instant. This is a pretty little contrivance whereby

the operator can cut at the very highest speed at all times without any danger of exceeding the capacity of his machine.

I would like to draw attention to section vii., paragraph 6, of Mr. Aldrich's paper. I think, with reference to using electric power in machine shops, that the reason set forth in the clause relating to portable tools is going to be of tremendous importance. The use of portable tools is so advantageous in vast numbers of shops that I think it is only necessary to see such tools used once to appreciate this fact. The electric motor makes such tools possible, and I think that will have a great influence on the future use of electricity in machine shops.

Mr. Reist.—Referring to the advantage of being able to vary the speed of motors, I might mention another application. That is, the possibility of varying the speed of the work while the machine is in motion, as, for instance, in the case of a boring mill. With such a machine it is desirable to keep a constant cutting speed while making a radial cut, independent of the diameter at which the turning is being done. This can readily be accomplished automatically by means of motors, but it could not be done to advantage by an ordinary drive from line of shafting.

Mr. S. T. Wellman.—One of the most useful places in which electricity has been applied for manufacturing purposes is around iron and steel works. It has been employed very successfully in all sorts of moving machines, rolling-mill tables, and for all purposes where small engines have heretofore been used, and the saving in money and the increase in the amount of work that is gotten out is something enormous. A very large measure of the increase of the work of the modern rolling mill to-day over what it was a few years ago is due to the application of electricity in these different ways, and I hope at some future meeting we shall have a paper dealing very fully with this application of electricity.

Mr. John Riddell.—Speaking of the economy of a direct-connected as compared with a belted motor, I would like to mention a 20-foot boring mill that had been running for about ten years with a belt drive. As it was an extension mill, more belts were required than would be necessary on a mill with stationary housings. In the case referred to there were eight belts in all. It will be understood by referring to the diagram (Fig. 436), that these eight belts were not all in use at the same time or when

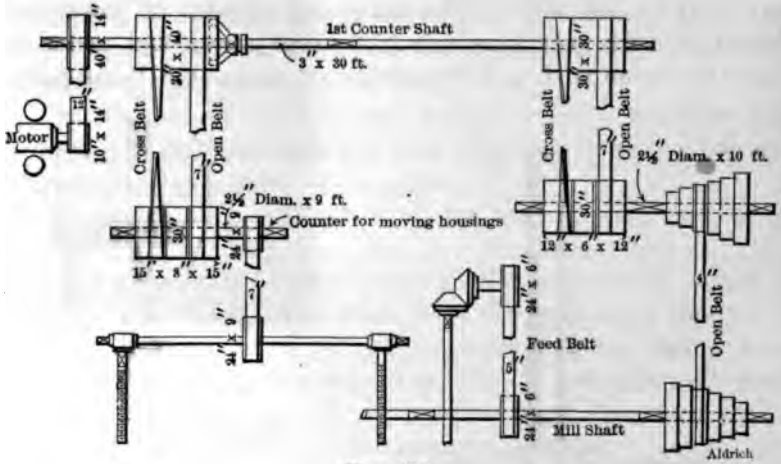

FIG. 436.

the mill was actually at work. There would, however, be four of them running when the table of the mill was turning.

In order to make a fair test between the two methods of driving, the mill was run in both cases at varying speeds, without

TABLE

SHOWING MATERIAL USED WITH BELT DRIVE.

12-inch double thick belt	26 feet
7- " " " "	161 "
5- " " " "	134 "
4- " " " "	60 "
Total number of feet of belt	381 feet
Number of feet of 3 -inch shaft	30 feet
" " " " 2½- " "	19 "
Number of 30-inch diam. pulley × 40-inch face	1
" " 30- " " " × 30- " "	1
" " 30- " " " × 15- " "	2
" " 30- " " " × 12- " "	2
" " 30- " " " × 8- " "	1
" " 30- " " " × 6- " "	1
" " 24- " " " × 9- " "	2
" " 24- " " " × 6- " "	2
" " 40- " " " × 14- " "	1
" " 10- " " " × 14- " "	1
" " clutches	1
" " hangers	7
" " cones	2

any work on the table. The maximum amount of power consumed with the belt drive was 10.6 horse-power, and under the same condition with a direct-connected motor 6.6 horse-power

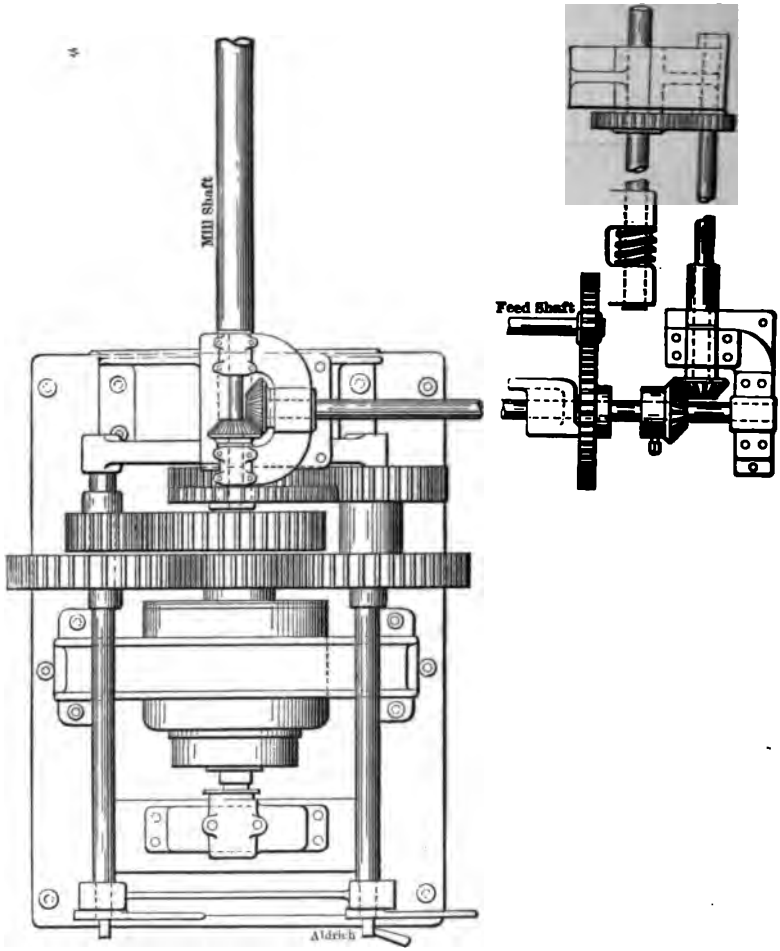

FIG. 437.

only was required, showing a saving of 4 horse-power in favor of the direct drive.

In connecting the motor direct to the mill, the armature was placed on a bronze bushing to run in the place which the cone originally occupied. In order to get the full range of speed required, one extra pair of back gears was put on, and we ex-

perienced no difficulty in getting a speed fast enough to bore or turn as small as 12-inch diameter, or slow enough to turn 20-foot diameter of steel casting.

The diagram of shafting and belts (Fig. 436), together with the table of material used, will give some idea of what is required to run a mill of this size with belts.

The sketch (Fig. 437) showing the direct connection speaks for itself.

I also know of a 10-foot planer that was originally driven by a motor and belts. The belts were replaced by a direct-connected motor through a pair of magnetic clutches, and on work 5 feet or 6 feet long it is safe to say that 25 per cent. more work can be turned out by this planer than when connected by the belt drive, because of the quick changes it makes.

It is almost impossible to run a planer of this size at a stroke of less than 3 feet, as nearly the whole of the stroke would be required to bring the platen up to speed ; whereas by the use of the clutches the platen is almost at speed at the moment of reversal, or at least before it has travelled 2 inches. The principal reason for this is that the clutches run in the same direction continuously, leaving nothing to be reversed but a light sleeve with a disk at either end, while with a belt drive the pulleys must be reversed. This also accounts for the saving of power at the time of reversal.

Connected with belts, the maximum power required was 34.67 horse-power at the moment of reverse to run back. Direct-connected, at the moment of reverse to run back, only 24.4 horse-power is required, a saving of over 10 horse-power for the direct connection. The power required on the cut and return remains practically the same as with the belt, but slightly in favor of direct connecting.

*Professor Aldrich.**—When the history is written of the introduction of electricity into manufacturing work, electrical engineers themselves will, no doubt, be somewhat blamed for many erroneous opinions and frequently unfounded arguments.

The several discussions have taken an interesting turn, especially with reference to the saving effected. Electricity requires no case of special pleading. It does not enter such a category. It is here and to stay. If you want to use it, do so and pay for

* Author's closure, under the Rules.

what you get. It is in its field perfectly analogous to the employment of skilled labor. Its introduction is not forced upon you. If you wish, accept what it offers; adopt it, and get more out of it per dollar invested, even as in the case of the piece-rate system, than you have gotten heretofore by any other plan. In other words, electricity enables you to do what you cannot do by any other system. It gives the operator that control, facility, and independence of action now absolutely essential from the standpoint of the management of men and of workshop ethics and economics. An operator can rarely be persuaded to speed up his machine with the belt system. Even if he could, the limit is soon reached. With an electric drive he does not hesitate to turn the lever, speed up the machine, and turn out more work per given expenditure of time and labor than his next-door neighbor. Almost all manufacturers recognize the advantage of it. The analogy between electric driving and the piece-rate system simply lies in a recognition, in dollars and cents, of what a workman is able to do. It is a question of the economy of production.

With reference to the alternating-current system, it is interesting to note that some manufacturers think that it is going to solve the whole problem. A case reported first-hand to me was that of an engineer in charge of an alternating-current installation, who stated that most singular phenomena were being observed; namely, that under no load the ammeter showed 78 ampères; under half load, 70 ampères; and under full load, 65 ampères; and that, therefore, the alternating current, *per se*, must be the thing, because you spend the least energy under full load.

Aside from this, however, the fact remains that the electric drive does give such increased production of an old machine that may bring it up to and very probably exceed that of an entirely new machine costing several thousand dollars more. On the other hand, if a new machine is placed in the factory and driven by belt transmission, its capacity is at once limited, and it is made to fall into line and keep gait with the old belt system. Why take an expensive machine tool with a skilled operator and harness it to a draught horse? Instances will occur to you where an old machine driven by electricity will exceed in output a thoroughly up-to-date machine tool driven by the belt system.

It is a simple question of what you are going to do about it;

that is, whether to put in new tools and drive them by belts, or to put in an electric drive for the tools you may chance to have on hand. Not even a fifth or sixth rate factory is going to work by candles or torches when it can have incandescent lights, for it is a very simple matter also to run a wire for this service. This is the question coming to the front: What are you going to do to increase the output? You cannot stand still, and yet there is perhaps very limited floor space. As has been indicated in the paper and in several of the discussions, it can be better solved by the electric drive than in any other way. When it comes to establishing a new factory, you cannot afford to drive modern machine tools in the good old way, unless you wish to limit the output instead of driving up to "the destructive limit" of the cutting tool. Work cannot be gotten out of cutting tools by the belt system that can be secured by using the electric drive. If the electric system is installed, tools may be worked up to "the destructive limit," as it has been termed, and therefore maximum output obtained under the most economic conditions, at the highest cutting speeds allowed by tool steel of the best grades furnished by the market.

No. 909,*

DRAFTING-ROOM AND SHOP SYSTEMS.†

BY FREDERICK O. BALL.

(Junior Member of the Society.)

THE systems which are about to be explained are not all suited to every kind of manufacturing business. Certain parts are, however, so general that they could with slight modifications be used to advantage in a great many shops.

The fundamental principle of these systems is that everything pertaining to the construction of the machines must originate in the *drafting room* and that everybody in the shop, including the foreman and all pattern makers, must be guided solely by the lists and orders emanating from that department.

The designing being done in the drafting room, that department should be made to assume the responsibility not only for the general design of the machines built, but for every part needed to make up a complete machine, and as the drafting room is without question the proper place to keep records of the machines built, it is quite evident that the machines should be built entirely according to its orders, so that the records may be accurately kept.

Before beginning the description of systems there is one thing I would like to say in regard to the communications between the

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* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*. It was originally presented and discussed at the Junior reunion of members, March 5, 1901, in New York City.

† For other discussions on this subject consult *Transactions* as follows:

No. 48, vol. ii., p. 369: "Method of Arranging and Indexing Drawings and Patterns." A. F. Hall.

No. 56, vol. ii., p. 576: "New Method of Keeping Mechanical Drawings." C. J. Porter.

No. 143, vol. v., p. 193: "Drawing Office System." H. R. Towne.

No. 596, vol. xv., p. 596: "Relation of the Drawing Office to the Shop in Manufacturing." A. W. Robinson.

No. 614, vol. xvi., p. 106: "Drawing Office Appliance." A. W. Robinson.

No. 910, vol. xxii., p. 1077: "Rules for a Drawing Office." A. W. Robinson.

different departments, viz., *verbal* orders or instructions should not be allowed.

The first subject to be considered will be Drawings and Tracings, they being first in the natural order of things.

The drawing we will dispose of at once, it being simply the necessary step to the making of a tracing. As soon as the tracing is made the pencil drawing is usually destroyed, being of no further use.

For tracings, the following rules have been found excellent:

1. Put only one piece on a tracing.

2. Do not put all views, of a piece requiring several views, on one tracing.

3. Keep down the sizes of tracings by drawing to as small a scale as will show clearly.

Rules 1 and 2 are somewhat elastic and can be stretched a little to cover exceptions.

I will now give you some of the reasons why the above rules are good, and the difficulties encountered if they are not followed.

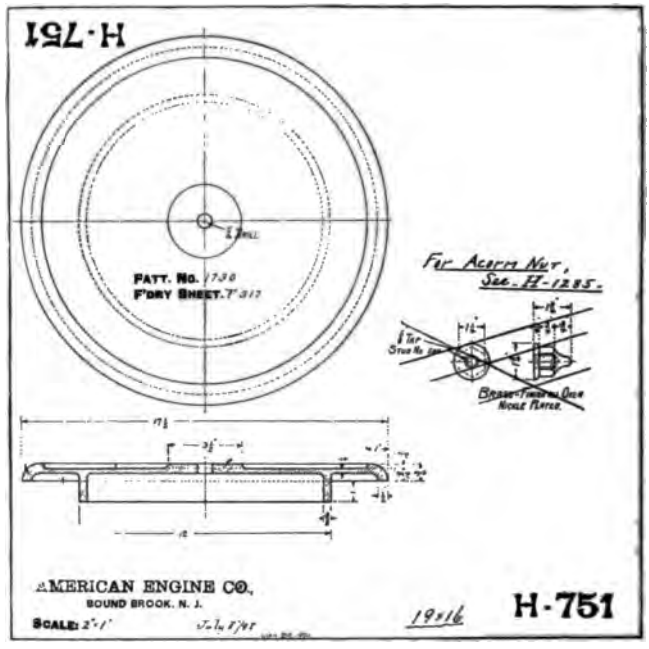
In the first place, if, as is very often the case, one piece should be used in a number of different sizes of machines, one tracing of it and one blue print in the shop is enough if it is on a tracing by itself. On the other hand, if it be shown on a sheet with other parts, and any one of these parts should be different or changed in any respect in making another machine, it would necessitate making a new drawing of all the parts on this drawing.

Having more than one part on a tracing would necessitate having more than one blue print in the shop so that the different parts can be made at the same time.

Another reason for singling out the pieces on tracings is that the oftener the tracings are reproduced the greater is the liability for mistakes to occur.

It will also be seen that, if after a piece has been shown on several tracings it should be found necessary or advisable to change this piece, an entire new set of tracings and blue prints would be required, whereas in the other case one new tracing and one new blue print would suffice.

To illustrate this point, refer to Fig. 438, which shows two tracings, one of them of a cylinder head plate with the acorn nut for holding it in place. This same nut is used with fifteen or twenty different plates, and if it had been traced with each plate there would have been that number of tracings of the same piece.


H-751
PATT. No. 1738
F'DRY SHEET. F-317
For Acorn Nut, See H-1285.
AMERICAN ENGINE CO.
BOUND BROOK, N. J.
SCALE: 2"-1'
1916
H-751

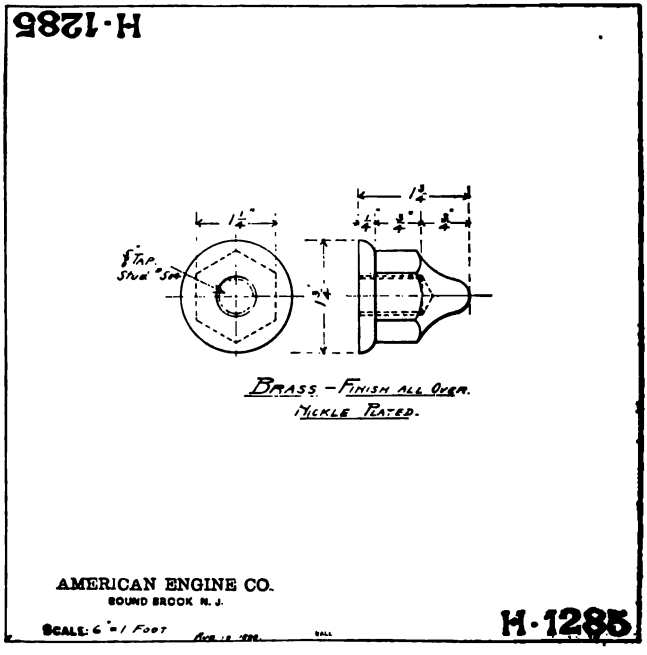

H-1285
BRASS - FINISH ALL OVER. NICKLE PLATED.
AMERICAN ENGINE CO.
BOUND BROOK N. J.
SCALE: 6" = 1 FOOT
H-1285

FIG. 438.

Rule 2 carries this idea a little farther. In the case of a piece requiring several views, these views should be grouped on several sheets so that changes in the piece can, if necessary, be made without making new tracings of all the views. Figs. 439 and 440 show this idea applied to a pair of cylinders. In this case two of the tracings K–919 and K–920 are used in connection with either K–918 for a pair of 16 and 30x18 cylinders or with K–941 for a pair of 15 and 30x18 cylinders.

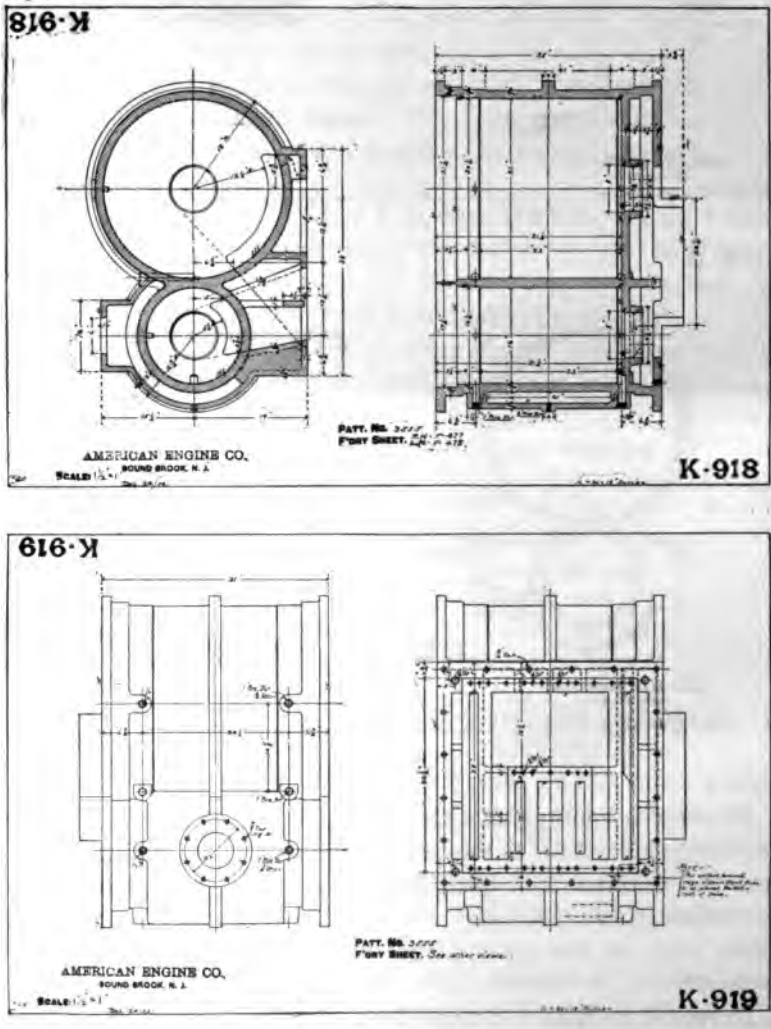


FIG. 439.

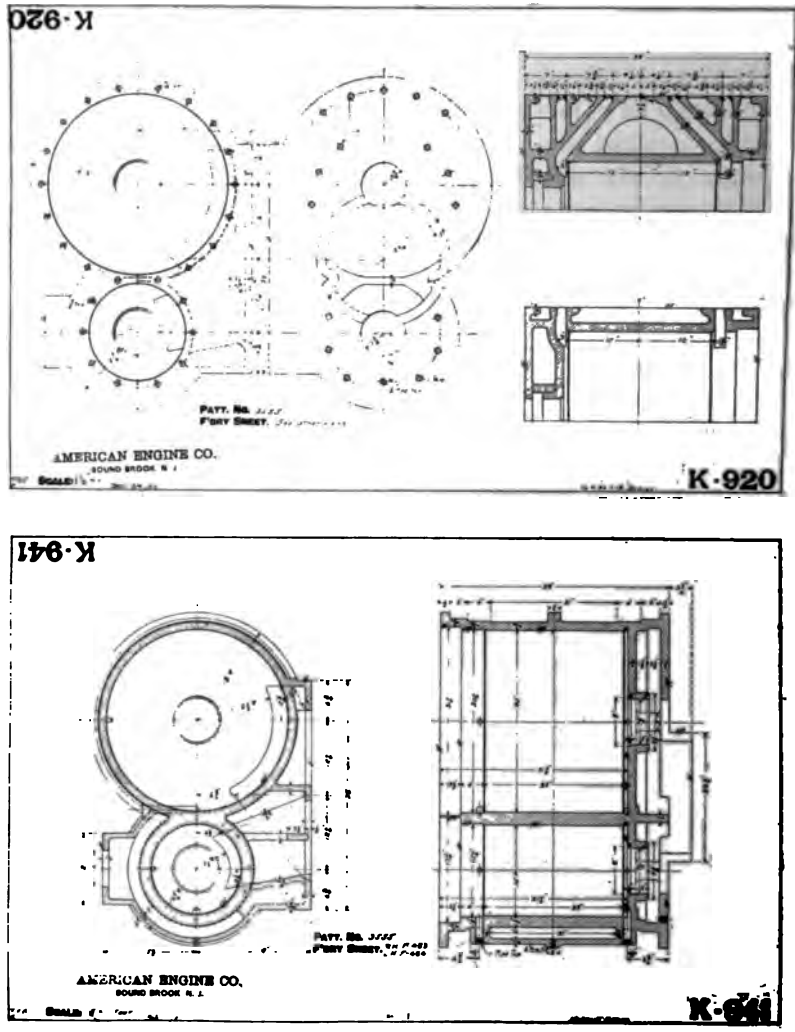


FIG. 440.

Another advantage of this rule is that when duplicate pieces are being worked on at the same time but not at the same process, the workmen can both have small blue prints showing the particular views necessary for their work, whereas if all the views were on one sheet, large duplicate blue prints would be necessary.

In regard to Rule 3, I have been greatly surprised to find that many of the largest manufacturing concerns in this country

make tracings almost as large as bed quilts (which name I have heard applied to them), when the same thing could have been shown equally well, or even better, on a tracing twelve by eighteen.

Before leaving the subject of tracings, I would like to call your attention to the information which should be entered on tracings. "Pattern Numbers," "Foundry Sheet," "Stud, Bolt, and Nut Numbers," "Jig Numbers," "Milling Cutter Numbers," "Finish Marks"; in fact, the more information you can put on a tracing the better. Most of these will be explained later. The subject "Finish Marks" can, however, be taken up here.

The amount of finish allowed on a pattern is usually left to the discretion of the pattern maker; but I do not think that it is a good plan, as he is not in a position to know, generally, how much finish is necessary.

He does not know whether a surface marked "finish" must finish perfectly and to the exact dimension or not, and consequently he always allows enough finish to insure a perfect surface when very much less finish would often be enough.

Certain castings on account of their shapes bulge and require less finish, while others warp and require more. Experience teaches us about these castings and when the information is once obtained it should be recorded on the tracings of them.

Below is shown a system of finish marks easily understood and quite convenient:

$f = \frac{1}{16}$ in. Finish.
$f = \frac{1}{8}$ " "
$F = \frac{3}{16}$ " "
$ff = \frac{1}{4}$ " "

More finish can be shown by increasing the number of F's indefinitely.

By referring again to Fig. 440 you will see the finish marks. This is one case where experience teaches us about finish. It is found that the steam-chest face on this cylinder always comes farther from the centre than intended, and instead of allowing $\frac{1}{4}$ inch finish, $\frac{1}{8}$ inch is always enough, and on some cylinders *no* finish is allowed on this surface.

The next subject will be that very important one in most manufacturing plants, viz.: "Patterns."

This will include a scheme for keeping a record of where the

different patterns are located, their foundry sheets, and the system for ordering castings.

Grouping the pattern numbers according to some plan for identification is generally found to be a great convenience. Whether or not the pattern numbers are thus grouped does not in any way affect the success of the following systems.

Fig. 441 shows a page of a convenient "Pattern Record Book." Each line is divided by vertical lines into four divisions, the number and name occupying the first. The second division is devoted to keeping a record of the location of the pattern, as will be shown later, while in the third and fourth divisions are entered the foundry sheets and tracing numbers, respectively.

When a tracing is made of a piece requiring a pattern, the name is entered in the pattern book next to the number selected for it. This *pattern number* is then entered on the *tracing*, and the *tracing number* is entered in the *pattern book* in the proper place.

As soon as the pattern is finished a foundry sheet for it is written up. These foundry sheets are written on sheets of tracing cloth of some convenient size and are numbered serially with an "F" prefixed to distinguish them.

Fig. 442 shows two of these sheets. You will notice that the *main piece* of the pattern has the pattern number *without* any letter, while every other piece of the pattern and every core box or piece of one has a number *with* some letter. The figures in the last column give the number of pieces.

You will also observe that, among the core boxes, certain parts are put together in brackets and the number of cores required is indicated. This makes it very easy for the core maker to get the core boxes together properly and tells him how many cores to make from each box.

This foundry sheet number is placed at once on the tracing *under* the pattern number and is entered in the Pattern Record Book.

Fig. 440 shows these numbers on the tracing, and Fig. 441 shows the Pattern Record Book with the foundry sheets entered in the proper place.

Fig. 443 shows a page of a book devoted to the shipment of patterns to the foundry. The postal card (Fig. 444) is for acknowledging receipt of patterns and is sent with slip enumerating the patterns to the foundry, by whom it is signed and returned.

Fig. 445 shows a page from a book for orderi the return of

Patt. No.	Name.	Location of Pattern.	Foundry Sheet No.	Tracing No.
3551	Falsehead Ring (high pressure) (16 + 30 × 18 inches)	1478	F-472	H-1234
3552	Falsehead Ring (low pressure) " " "	1478	F-472	H-1234
3553	Valve (16 + 30 × 18 inches)	1476	F-472	H-1230
3554	Valve Cover (16 + 30 × 18 inches)	1475	F-472	H-1231
3555	Cylinders (16 + 30 × 18 inches) (15 + 29 × 18 inches)	1469	F-477, 478, 479, 480, 483, 484	K-918, 919, 920, 941
3556	Cylinder Head (high pressure) " " "	1475	F-472	H-1227, 1278
3557	Cylinder Head (low pressure) " " "	1475	F-481	H-1227, 1278
3558	Piston (30-inch) (6-inch thick)	1476	F-481	K-915
3559	Piston Rings (30-inch)	1475	F-481	H-1235
3560	Rock Arms on shaft (16 + 30 × 18 inches)	1502—R-583—1475	F-481, 485	H-1236, 1238
3561	Cylinder Jacket (high pressure), side (16 + 30 × 18 inches)	1491—R-576—1477	F-481	K-916
3562	Cylinder Jacket (high pressure), bottom " " "	1478—R-569—1467	F-481	K-916
3563	Cylinder Jacket (low pressure), top " " "	1478—R-569—1465	F-481	K-917
3564	Cylinder Jacket (low pressure), middle " " "	1491—R-576—1477	F-481	K-917
3565	Cylinder Jacket (low pressure), bottom. Frame end	1506—R-588—1496	F-481	K-917
3566	Cylinder Jacket (low pressure), " Head end	1497—R-581—1487	F-481	K-917
3567	Crosshead Shoe (phosphor-bronze)	1499	F-485	K-943
3568	Counterbalance	1497	F-481	H-1279
3569				
3570				
3571				
3572				
3573				
3574				
3575				
3576				
3577				
3578				
3579				
3580				
3581				

FIG. 441.—PATTERN RECORD BOOK.

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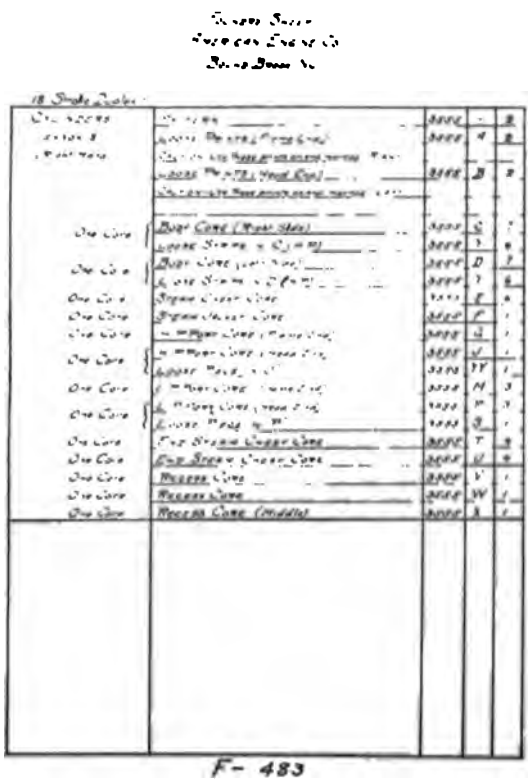

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FIG. 449.—FOUNDRY SHEETS.

patterns. The postal card (Fig. 446) is filled out and mailed to the foundry as soon as the patterns have been received.

Both of these books just shown are numbered serially. In the latter an "R" precedes the number, indicating that it is a return order.

1469

AMERICAN ENGINE CO.,

BOUND BROOK, N. J., *Jan. 2nd*, 1901.

Pattern shipped to FORAN FOUNDRY & MFG. CO.

Cylinder	3555		2
	"	A	2
	"	B	2
	"	C	7
	"	D	7
	"	E	6
	"	F	1
	"	G	1
	"	H	1
	"	J	1
	"	K	1
	"	M	3
	"	N	1
	"	P	3
	"	S	1
	"	T	4
	"	U	4
	"	V	1
	"	W	1

Continued 1470.

FIG. 443.

To the AMERICAN ENGINE CO.

Jan. 4, 1901.

We have this day received your pattern and core boxes, as per your slip No. 1469.

FORAN FOUNDRY & MFG. CO.

FIG. 444.

R—583

BOUND BROOK, N. J., *Feb. 6th*, 1901.

To FORAN FOUNDRY & MFG. CO.

Please ship the following patterns to AMERICAN ENGINE CO.

Rock arms on shaft.....	3560	.....	1
C. P. M.			

FIG. 445.

To FORAN FOUNDRY.

BOUND BROOK, N. J., *Feb. 10th*, 1901.

We have this day received patterns as per our slip.

R—583

AMERICAN ENGINE CO.
Per F. O. B.

FIG. 446.

In sending away or ordering the return of patterns, each piece is enumerated. The number of this order is then entered *in pencil* in the second column of the Pattern Record Book (See Fig. 441). If the last entry in this column has an "R" before it, it indicates that the pattern is at home, while if without an "R" it is away, and by referring to the stub indicated its location is at once known. It is found convenient to enter these from right to left, as the "R" is then brought into prominence.

Fig. 447 shows a form of order used for ordering castings. All

AMERICAN ENGINE CO.

FOUNDRY ORDER M 2860 *March 10th*, 1901.

To FORAN FOUNDRY & MFG. CO.

BLUE PRINT NO.	PATTERN NO.	DESCRIPTION OF PATTERN.	FOUNDRY SHEET.	NO. REQUIRED.	TALLY.
K-919 K-920 K-941	3555	Cylinder (R. H.) 15 + 30 × 18 O. K. Draughting Room. F. O. B.	F-483	1	

FIG. 447.

orders for castings *must* go through the draughting room for their approval as to the "Blue Print Nos.," "Patt. No.," and Foundry Sheet, as well as to make sure that the pattern is at the foundry to whom the order is made out.

This order you will notice is made out for 1 Cylinder (right hand) 15 and 30 x 18, and refers to B. P.'s K–919 and 920 and 941 (see Figs. 439 and 440).

Looking at these tracings we see on K–941 that the foundry sheet is F–483, which agrees with that on the order.

Fig. 442 shows this foundry sheet as well as that for the L. H. cylinder of the same size.

Fig. 448 shows the foundry sheets referred to on K–918 of Fig. 439 for 16 and 30 x 18 cylinders Right and Left hand.

Referring in the Pattern Record Book (Fig. 441) to No. 3555, we see that the last entry for the location is 1469. Turning to this number in the book for shipping patterns (see Fig. 443), we find that the pattern and core boxes are at the proper foundry, so that the order is correct and can be O. K.'d by the drafting room.

This order before going to the foundry must be copied on to the stub.

This system for the manipulation of patterns is so general in its application and so perfect in its operation that there can be no doubt as to its success in any kind of a manufacturing business where patterns are used.

To make these foundry sheets necessitates a certain amount of work, but when this is once done it is done for all time. When foundry sheets are not used or accurate records of patterns kept, it means that one pattern maker, generally the chief, is kept busy the greater part of his time matching up patterns and core boxes and comparing them with the drawings to see that they are correct, to say nothing of the money spent in making new pieces to replace those lost.

By the system of foundry sheets and accurate records this is entirely obviated and there can be no question as to its great merit as an economizer of time, money, and worry.

Figs. 449 and 450 will give an idea of the flexibility of this foundry sheet system. These three foundry sheets are for three different cylinder castings, and you will notice that the three main patterns have different numbers. If you will observe further, you will find that certain parts of core boxes are used for each of the cylinders, and in one case a body core with still another pattern

Foundry Sheet
American Engine Co
Bound Brook, NJ

18" Stroke Duplex.

Cylinders 16 × 30 × 18 (Left Hand)	Pattern	3555	–	2
	Loose Prints (Frame End)	3555	A	2
	Caution – Use these prints on end marked 'Left'			
	Loose Prints (Head End)	3555	B	2
	Caution – Use these prints on end marked 'Right'			
One Core	Body Core (Left Side)	3555	C	7
One Core	Body Core (Right Side)	3555	D	7
One Core	Steam Chest Core	3555	E	6
One Core	Steam Jacket Core	3555	F	1
One Core	H. P. Port Core (Head End)	3555	G	1
One Core	Loose Piece in 'G'	3555	H	1
One Core	H. P. Port Core (Frame End)	3555	J	1
One Core	L. P. Port Core (Head End)	3555	M	3
One Core	Loose Piece in 'M'	3555	N	1
One Core	L. P. Port Core (Frame End)	3555	P	3
One Core	End Steam Chest Core	3555	T	4
One Core	End Steam Chest Core	3555	U	4
One Core	Recess Core	3555	V	1
One Core	Recess Core	3555	W	1
One Core	Recess Core (Middle)	3555	X	1

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Foundry Sheet
American Engine Co
Bound Brook N J

18 Stroke Duplex

Cylinders 16 × 30 × 18 (Right Hand)	Pattern	3555	–	2
	Loose Prints (Frame End)	3555	A	2
	Caution – Use these prints on end marked 'Right'			
	Loose Prints (Head End)	3555	B	2
	Caution – Use these prints on end marked 'Left'			
One Core	Body Core (Right Side)	3555	C	7
One Core	Body Core (Left Side)	3555	D	7
One Core	Steam Chest Core	3555	E	6
One Core	Steam Jacket	3555	F	1
One Core	H. P. Port Core (Frame End)	3555	G	1
One Core	H. P. Port Core (Head End)	3555	J	1
	Loose Piece in 'J'	3555	K	1
One Core	L. P. Port Core (Frame End)	3555	N	3
One Core	L. P. Port Core (Head End)	3555	P	3
	Loose Piece in 'P'	3555	S	1
One Core	End Steam Chest Core	3555	T	4
One Core	End Steam Chest Core	3555	U	4
One Core	Recess Core	3555	V	1
One Core	Recess Core	3555	W	1
One Core	Recess Core (Middle)	3555	X	1

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FIG. 448.—FOUNDRY SHEETS.

Foundry Sheet
American Engine Co
Bound Brook N.J

12 Stroke
Cross Compound

13 Cylinder H.P	Pattern	1311	—	1
	Loose Boss for Steam	1311	A	1
	Loose Boss for Exhaust	1311	B	1
One Core	Main Steam Chest Core Box	1201	C	1
	Horse Shoe Port Pieces	1201	D	2
	Covering Pieces	1201	E	2
	Segments for Stopping off Ports	1311	C	2
	Chipping Strips	1201	G	8
One Core	Small Steam Chest Core Box	1201	H	1
	Port Pieces	1201	J	4
	Chipping Strips	1201	K	8
One Core	Exhaust Chamber Core Box	1201	L	2
	Steam Opening Round	1311	D	1
	Steam Opening Long	1311	E	2
	Exhaust Opening Round	1311	F	1
Two Cores	Covering Core	1201	R	1
Two Cores. 15	Body Core	1311	G	1
24 Cylinder L.P	Pattern	1313	—	2
	Loose Indicator Bosses	1313	A	4
Two Cores	Main Core Box	1313	B	1
	Loose Prints in B for Port Cores	1313	C	2
Two Cores	Valve Chest Core Box	1313	D	1
	Loose Prints in D	1313	E	4
Two Cores	Exhaust Chamber Core Box	1313	G	4
One Core	Steam Chamber Core Box	1313	K	1
Two Cores	Steam Port Core Box	1313	M	1
One Core	Recess Core on D	1313	N	3
24 Valve L.P	Pattern	1302	—	1
	Core Box	1302	A	2

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Foundry Sheet
American Engine Co.
Bound Brook - N.J

14 x 12

Cylinder	Pattern	1201		1
	Loose Boss for Steam	1201	A	1
	Loose Boss for Exhaust	1201	B	1
One Core.	Main Steam Chest Core Box	1201	C	1
	Horse-Shoe Port Pieces	1201	D	2
	Covering Pieces	1201	E	2
	Segments for Stopping off Ports	1201	F	2
	Chipping Strips	1201	G	8
One Core	Small Steam Chest Core Box	1201	H	1
	Port Pieces	1201	J	4
	Chipping Strips	1201	K	8
One Core	Exhaust Chamber Core Box	1201	L	2
	Steam Opening, Round	1201	M	1
	Exhaust Opening, Round	1201	N	1
	Steam Opening, Long	1201	P	1
Two Cores.	Covering Core	1201	R	1
Two Cores. 14	Body Core	1201	S	1
Two Cores. 13	Body Core	1201	T	1
Cylinder Head	Pattern	1202		1
False Head	Pattern	1203		2
	Core Box	1203	A	1
Valve (Outside Sleeve)	Pattern	1204		1
	Core Box	1204	A	2
Valve (Inside Sleeve)	Pattern	1205		1
	Core Box	1205	A	2
Valve Nut	Pattern	1206		1
Steam Chest Cover	Pattern	1207		1
Cylinder Head Plate	Pattern	1208		1
Piston Gland	Pattern	1209		1
	Core Box	1209	A	1

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FIG. 449.—FOUNDRY SHEET.

Foundry Sheet
American Engine Co
Bound Brook N.J.

Cylinder	Pattern	1511	—	1
	Loose Boss for Steam	1511	A	1
	Loose Boss for Exhaust	1511	B	1
One Core	Main Steam Chest Core Box	1201	C	1
	Core Box Bottom	1511	C'	1
	Spacing Pieces	1511	D	4
	Horse-shoe Port Pieces	1201	D	2
	Covering Pieces	1201	E	2
	Segments for Stripping off Ports	1201	F	2
	Chipping Strips	1201	G	8
One Core	Small Steam Chest Core Box	1201	H	5
	Port Pieces	1201	H'	4
	Chipping Strips	1201	K	8
	Exhaust Chamber Core Box	1511	E	1
One Core	Steam Opening (Round)	1201	M	1
	Exhaust Opening (Round)	1201	N	1
	Steam Opening (Long)	1201	P	1
Two Cores	Covering Core	1201	M	1
Two Cores 11	Body Core	1511	F	1
Two Cores 12	Body Core	1201	S	1
Iron Base	Pattern (Same for 1441-E)	1441	—	1
	Loose Piece on Side	1210	—	1
One Core	Crank End Core	1441	A	1
One Core	Loose Pieces	1441	B	2
	Head End Core	1441	A	1
One Core	Middle Core	1441	C	1
One Core	Core for Side Piece	1210	A	1
Three Cores	Foundation Bolt Core Box	1441	D	2
Cylinder Jacket	Pattern	1215	—	1
Cylinder Jacket	Pattern	1213	—	1
Cylinder Jacket	Pattern	1218	—	1
Cylinder Jacket	Pattern	1219	—	1

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FIG. 450.—FOUNDRY SHEET.

number is used, there being in this case parts from three different patterns used in making the cylinder.

With a system like that just referred to, the matter of making castings is not one of tradition or memory and the work can be transferred from one foundry to another without causing any delay other than that concerned in moving the patterns, and it is not necessary to give any instructions to the new foundry other than that furnished by the system.

To keep an accurate record of all blue prints at the foundry and in the shop is quite necessary.

Fig. 451 shows a page from a book for recording all blue prints at the foundry. The postal card shown with it (Fig. 452) is attached to the blue prints sent to the foundry to be signed and returned. It is a good plan in sending blue prints to the foundry to date them with soda. Then if the postal card orders the pre-

vious print destroyed, there is no chance of the foundry destroying the wrong one.

Size "F."

B. P. No.	Postal Card No.	B. P. No.	Postal Card No.	B. P. No.	Postal Card No.
201	86	226	86	251	184
202	120	227	120	252	113
203	120	228	120	253	113
204	118	229	120	254	89
205	120	230	189	255	120
206	120	231	117	256	117
207	120	232	120	257	120
208	130	233	120	258	120
209	120	234	120	259	86
210	120	235	86	260	88
211	86	236	117	261	88
212	205	237	198	262	123
213	119	238	120	263	120
214	120	239	86	264	120
215	120	240	79	265	120
216	120	241	130	266	120
217	120	242	130	267	117
218	120	243	130	268	113
219	120	244	117	269	120
220	120	245	117	270	138
221	120	246	120	271	120
222	123	247	120	272	113
223	120	248	117	273	120
224	86	249	120	274	86
225	120	250	155	275	113

FIG. 451.

No. 86. *Jan. 1st*, 1901.

AMERICAN ENGINE CO.:

We have this day received the following blue prints F–201–211–224–226–235–239–259–274.....

and have destroyed previous copies of same.....

.....

Yours truly,

FORAN FOUNDRY.

[You can take an impression copy of this.]

FIG. 452.—BLUE PRINTS TO FOUNDRY.

Size "K."

B. P. No.	Unmoun'd	Mounted	B. P. No.	Unmoun'd.	Mounted.	B. P. No.	Unmoun'd.	Mounted.
851			876	.....	10 10 00	901	12, 15, 00	1/18/01
852	.....	10 10 00	877	.....	10 30 00	902	.....	1/10/01
853	.....	10 10 00	878	.....	12 26 00	903	.....	1/18 01
854	.....	2 1 01	879	.....	12 26 00	904	12, 21, 00	1/18/01
855	.....	2 1 01	880	.....	12 26 00	905	.....	1/31/01
856	.....	10 10 00	881	.....	12 26 00	906		
857	.....	10 10 00	882	.....	12 26 00	907	1/9/01	2/21/01
858	.....	1 24 00	883	.....	12 26 00	908	.....	1/18 01
859			884	.....	12 26 00	909	.....	1/18/01
860			885	.....	12 26 00	9 0	.....	1/18/01
861			886	.....	12 26 00	911	.....	1/18/01
862			887	.....	12 26 00	912	.....	1 18/01
863	.....	1 24 01	888	.....	12 26 00	913	.....	1/18/01
864	.....	10 10 00	889	.....	12 26 00	914	.....	1/18/01
865	.....	10 10 00	890			915	.....	1/18/01
866			891	.....	12 26 00	916	.....	1/18/01
867			892	.....	12 26 00	917	.....	1/18/01
868			893	.....	1 18 01	918	.....	1 24/01
869	.....	10 10 00	894	.....	12 26 00	919	.....	1 24 01
870	.....	10 30 00	895	.....	12 26 00	920	.....	1/24/01
871	.....	10 10 00	896	.....	12 26 00	921		
872	.....	10 10 00	897	.....	12 26 00	922		
873	.....	10 10 00	898	.....	12 26 00	923	1/25/01	.....
874			899	.....	12 26/00	924	.....	1/18/01
875	.....	10 10 00	900	.....	12/26/00	925	.....	1/18/01

FIG. 453.—BLUE PRINTS TO SHOP.

Fig. 453 shows a page from a book for keeping a record of every blue print in the shop either mounted or unmounted. The date in the first column after the number indicating an unmounted blue print, and in the second a mounted print.

I would like to call your attention to the postal card system of securing acknowledgments. The great advantages of this are that it eliminates the possibility of the fellow at the other end forgetting to send acknowledgments, besides putting these records in a very convenient form.

Another very important part of a well-conducted manufacturing business is that pertaining to *records* of *machinery* shipped. It is essential that these records shall not depend upon the memory of any one for their success.

There are in this country to-day numbers of large manufacturers, building the most up-to-date machinery, who, if requested to forward certain parts to repair a broken machine, will ask for a working sketch of the parts wanted. This greatly delays the starting up of the broken machine, and is generally very annoying.

The following system operates very successfully in the engine

business and would without doubt be readily adaptable to other lines of manufacture.

The general scheme is to preserve a copy of the shop list of blue prints from which each engine is made.

Fig. 454 shows one of these lists. A convenient way is to have these lists printed on a very thin bond paper from which good blue prints can be made for use in the shop.

You will notice at the top of this sheet places for the "Name of Purchaser," "Size of Engine," and "Class." It is not at all neces-

FOR U.G.I. Co.

SIZE OF ENG. " 15×30×18 " CLASS " D-260 " Std.-Belted.

	H. P.	L. P.	Both.
Assembled Drawing,	—	—	—
Balance Wheel,	—	—	K-931
Connecting Rod Assembled,	—	—	P-256
Connecting Rod and Straps,	—	—	K-889
Connecting Rod Boxes, Keys and Bolts,	—	—	K-901
Counterbalance,	—	—	H-1219
Crank Shaft,	—	—	P-261
Crank Shields,	—	—	K-903
Crosshead and Pin,	—	—	K-900
Crosshead Shield,	—	—	H-1221
Cylinder,	H-919, 920, 941		
Cylinder Head,	—	—	H-1275
Cylinder Head Plate and Acorn Screw,	H-911	H-752	—
Cylinder Jacket,	H-916	K-917	—
Dynamo Base,	—	—	—
Exhaust Flange,	—	—	H-764
Frame,	H-1149 P-257, 258, 259, 260		
Frame Bolts,	—	—	—
Foundation Bolts, Plates and Nuts,	—	—	H-1226
False Head, Rings	—	—	H-1234
False Head Support and T,	—	—	—
False Head Support Box,	—	—	—
Guide, (Lower),	—	—	K-892
Guide (Upper), and Guide Pillars,	—	—	K-934
Guide Bolts,	—	—	K-904
Indicator Plugs,	—	—	H-674
Indicator Rig, (Piper H-1232)	—	—	H-943
Iron Base,	—	—	H-912
Oil Pipes,	—	—	H-1224
Oil Pump,	—	—	K-524
Oil Tank,	—	—	H-1201
Oil Sight Connections and Union,	—	—	H-183
Oil Sight Feed,	—	—	H-204
Oil Pump Air Chamber,	—	—	H-203
Outboard Bearing,	—	—	—
Pillow Block Cap and Gib,	—	—	H-1217
Pillow Block Babbit Liners,	—	—	H-421
Pillow Block Oil Discs,	—	—	H-41
Piston Complete,	K-945	K-915	—
Piston Rings,	H-365	H-1235	—
Piston Gland,	H-1007	H-1220	—
Main Pins Crank & Link	—	—	H-1200

Condensing	H. P.	L. P.	Both.
Rock Shaft Bracket (Complete),	—	—	K-891
Rock Arms on Shaft, Pin and Caps,	—	—	H-1236
Steam Chest Cover,	—	—	H-1202
Throttle Assembled,	—	—	K-902
Throttle Body,	—	—	—
Throttle Yoke and Hand Wheel,	—	—	—
Throttle Details,	—	—	—
Valve,	—	—	H-1230
Valve Rings,	—	—	—
Valve Stem,	—	—	H-1225
Valve Stem Head,	—	—	H-255
Valve Stem Stuffing Box,	—	—	H-153
Valve Chest Yoke,	—	—	—
Valve Chest Yoke Details,	—	—	—
Valve Chest Cover,	—	—	—
Valve Stem Gland,	—	—	—
Valve Stem Support,	—	—	—
Valve Stem and Valves Complete,	—	—	—
Eccentric and Pin,	—	—	—
Eccentric Strap,	—	—	—
Eccentric Cafrier, Bushing and Bolt,	—	—	H-1223
Eccentric Carrier Crank Pin & Link Stud,	—	—	H-1223
Eccentric Rod,	—	—	K-910
Eccentric Rod Head, (Brass),	—	—	H-255
Eccentric Rod Head, (Cast Iron),	—	—	H-37
Governor Wheel,	—	—	T.H. H-908, L.H. H-909
Governor Assembled,	—	—	—
Governor Link,	—	—	Rod H-758, End H-758
Eye Bolt and Screws	—	—	H-1237
Weight, Weight Bolt and Link Stud,	—	—	K-907
Steam Chest	—	—	H-1206
" " Cover Plate	—	—	H-1208
Trough for Valve Stem Drip	—	—	H-1215
Valve Cover	—	—	H-1231
" " Supports	—	—	H-1204
Hand Hole Cover	—	—	H-1044
Stuffing Boxes	H-1218	H-1214	—
Indicator Plug Bosses	—	—	H-897
Drip Pipes	—	—	H-1233
Foundation Templates	—	Iron Base H-1263, Brick - H-1264	

Fig. 454.

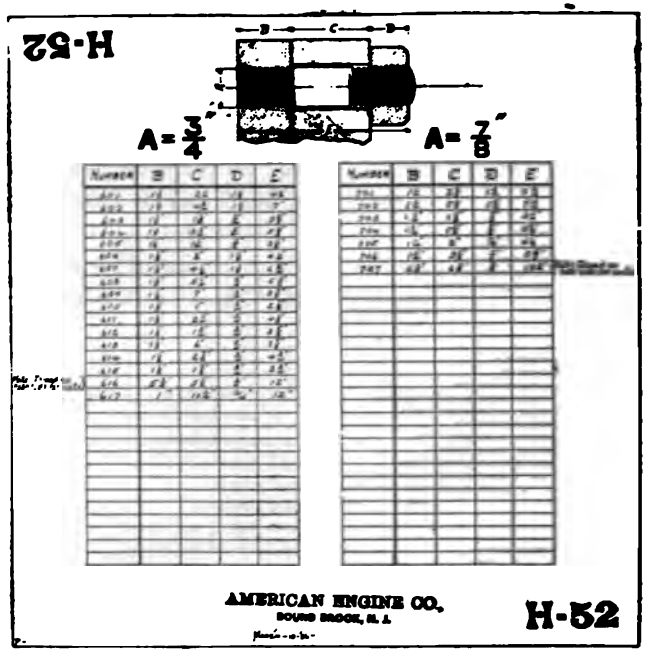

FIG. 455.

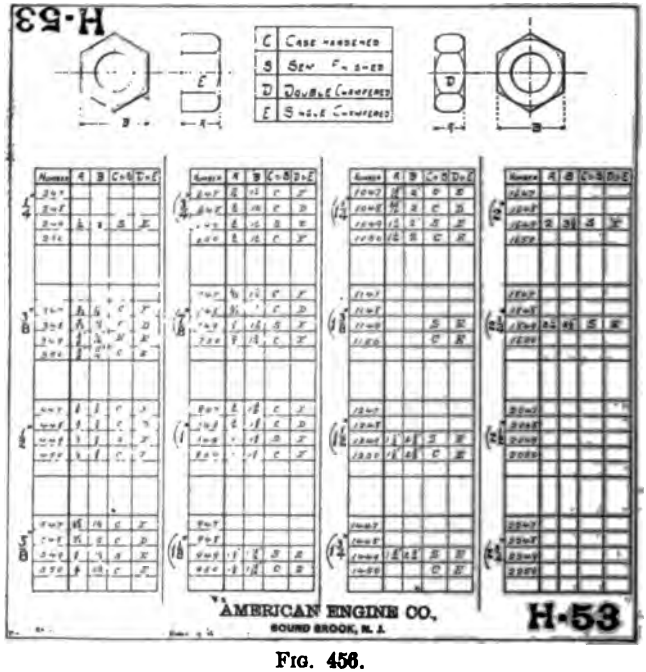

FIG. 456.

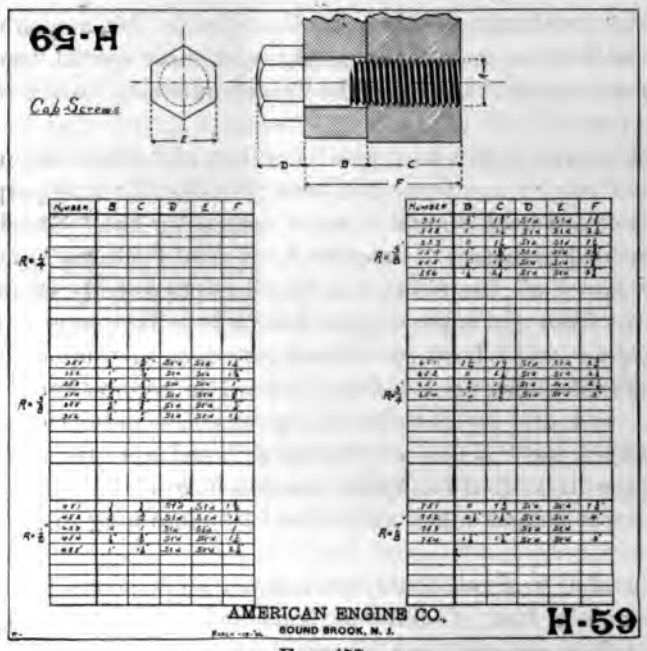

FIG. 457.

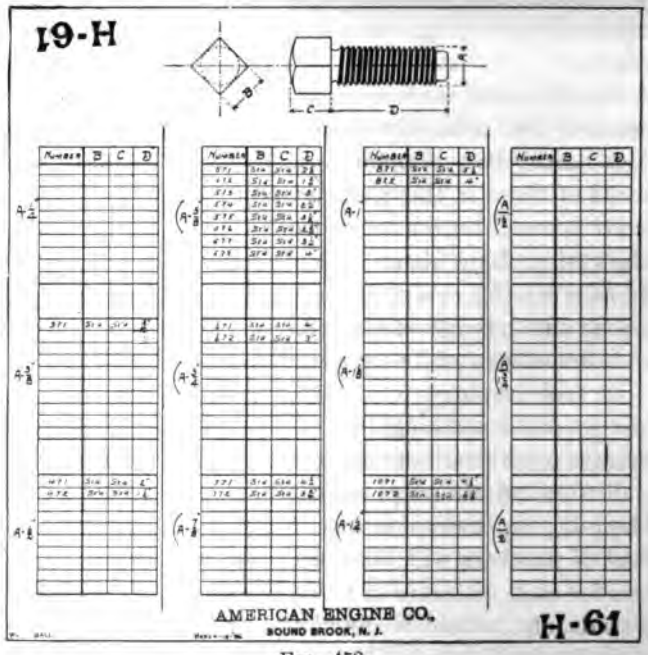

FIG. 458.

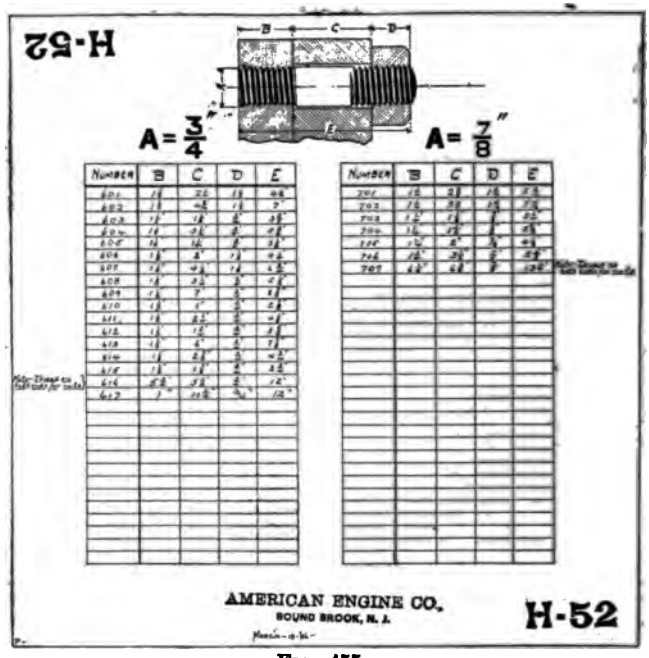

FIG. 455.

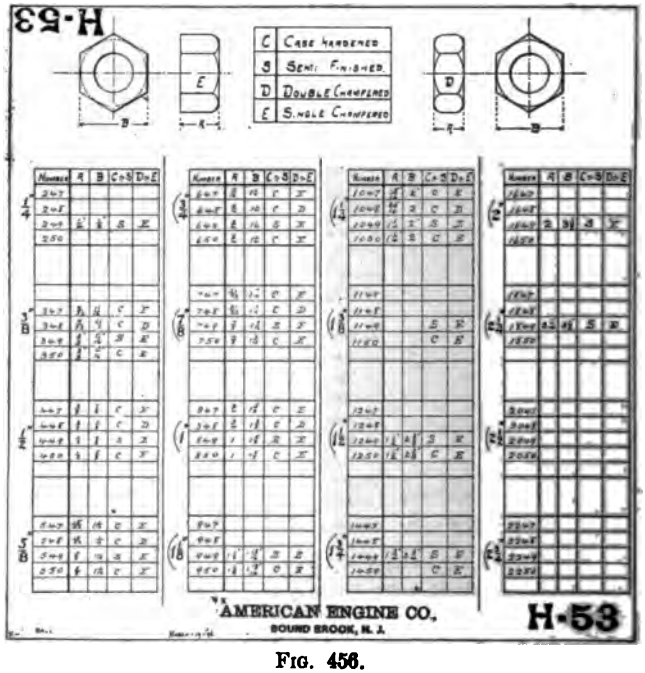

FIG. 456.

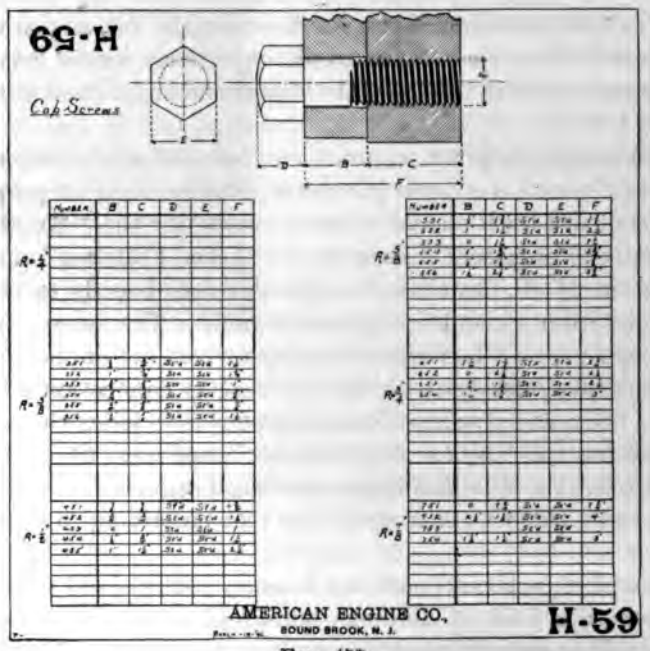

FIG. 457.

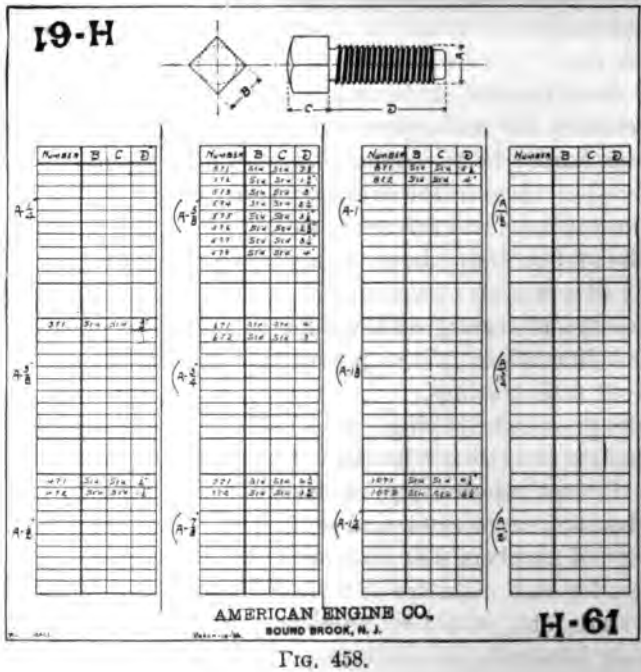

FIG. 458.

sary to have the name of the purchaser on the list, as you will see later, but it is put there for convenience on some special lists. The important datum at the top is the Class number, as I will now show you.

Each engine is given a serial number, and when shipped the complete record is entered in a book provided for that purpose.

This record book should contain spaces for the "Serial No.," "Name of Purchaser," "Location," "Special Features," and, most important of all, the *Class No.*, which refers directly to the blue print list from which the engine was built. The same *Class No.* will appear in this book for all engines which are duplicates.

A suitable index book should be used in connection with this record book, and it will be found convenient to index the machine both under the "Name of Purchaser" and also the city where located, as this often facilitates the identification of a machine.

The next subject taken up will be that pertaining to studs, nuts and bolts.

Most of us, without doubt, are familiar with the old sample system where a host of different bolts and screws, etc., adorn the walls. This system is so obviously bad that it would be a waste of time to point out its defects when the time can be so much better employed in showing you a better system and enumerating *its good* points.

The dimensions of studs, nuts, and bolts used in the manufacture of machinery are naturally determined in the drafting room, and there can hardly be two opinions as to the desirability of keeping the record of these in the drafting room, and to have them in the most convenient form for reference.

In the system I am about to explain the principal feature is the making of a tracing of a stud, bolt, or nut with letters in place of dimensions and having on the same sheet a table where the numbers and dimensions of the pieces are entered. Figs. 455 to 458 show four such tracings.

In the practical working out of this scheme it is found a great convenience to so distribute the numbers that the size and number bear a distinct relationship, especially in the standard pieces such as studs, nuts, cap screws, and set screws. The following apportionment of numbers will be found very convenient. Allow 100 numbers for each diameter of thread advancing by eighths. Thus $\frac{3}{8}$-inch studs, etc., would be numbered in the five hundreds, $\frac{4}{4}$-inch in the six hundreds, etc.

Now to make it uniform let all studs be numbered in the same division of the hundred, nuts in another, cap screws in another, etc. This will be found especially convenient in the four standard nuts of each size, as the same kind of nut of the different sizes will have the last two figures the same for all sizes, and the size will be determined by the first figure or figures.

Blue prints of these sheets can be sent to the manufacturers of these pieces, and studs, bolts, nuts, etc., ordered by number.

In designing a piece of machinery, the stud, bolt, and nut numbers necessary should be entered on the tracing. This should be compulsory, as it not only insures against the possibility of not having the proper studs, nuts, and bolts, but is of great assistance to the workmen who erect the machines.

Another advantage of this scheme is that, having the dimensions of all studs and bolts in a convenient form before the draftsmen, the number of different sizes does not increase more than is absolutely necessary, as the part being designed can frequently be changed slightly to use some stud or screw already on the lists.

The foregoing systems have all been for use in the drafting room. The next subject taken up will be "Labor Cost" and "Cost of Material," of a series of manufactured articles.

Taking up first the question of "Labor Cost" in a shop where standard machines are manufactured in lots, it is customary to make these lots large enough to secure low cost of manufacture, and ordinarily the labor cost is kept as a whole. The following are some of the defects of the system:

It generally happens that the machines are not all assembled and shipped promptly, and in consequence, the order remains open until the completion of the last machine. This greatly delays the desired information as to cost, and the information when obtained is on the machine as a whole, and nothing is known as to the cost of the separate parts.

Ordinarily, the number of machines comprising a lot is found to be either too small for the economical manufacture of some parts or unnecessarily large for some of the other parts.

Then, too, if orders should become mixed, the information obtained is valueless, and the time and labor to obtain the information has been wasted.

In some lines of manufacture the following system will be found to obviate the defects just referred to.

The general plan is to find the labor cost of the several parts by manufacturing them on separate shop orders, and then, by aggregating these costs, the total labor cost of the machine is obtained.

This system greatly facilitates the locating of excessive labor costs, and is also very convenient in determining the selling prices of the parts.

The greatest advantage, however, is that the number of pieces in each lot can be determined entirely with reference to securing the best results in the manufacture of that part.

Having obtained the labor cost of the several parts by any of the usual methods, it will be found convenient to record this cost in a book, or on cards similar to that shown in Fig. 459. The repeated records thus obtained show whether the cost is increasing or decreasing. They will be found very convenient, not only for comparing the successive orders of each size, but also the relative costs of the different sizes, and where intermediate sizes have not been built, their probable costs are easily obtained by interpolation.

At intervals the average costs of the several sizes can be found as shown on Fig. 459 and a convenient method for aggregating

Shop Order No.	8½ x 8	10 x 10.	12 x 11.	14 x 12.	15 x 14.	16 x 16.	Shop Order No.
10	$4.60				$8.00		30
20			$6.00	$7.00			50
40		$5.00				$9.00	60
70		4.75			8.25		80
100	3.75			6.75			90
110			6.00			8.00	120
130	3.50			6.25			150
140		4.50				8 50	160
170			5.50		7.50		180
Average	3.75	4 75	5.80	6.60	7.90	8.50	Average, Jan. 6th, 1901.
190	3.75				7.75		200
210			5.75	6.75			220
240		4.75				8.75	230
250		4.50			8.00		260
270	3.50			6.50			280
290			5.75			7.75	300
310	3.25			6 00			320
330		4.25				8.25	340
350			5.25		7.25		360
Average..	3.50	4.50	5.50	6.40	7.69	8.25	Average, March 8th, 1901.

FIG. 459.—LABOR ON CRANK SHAFTS (SIMPLE).

these costs is shown by Fig. 460. The entries here should be made in pencil and revised whenever required.

When the different parts of machines are brought into the shop in varying quantities, it becomes necessary to keep a record of the number of each on hand. This is especially necessary with those parts which require a long time for their production.

A convenient form for keeping these records is a stock ledger where opposite pages are devoted to the same subject, both being arranged to cover all the sizes, one page showing the number of each on hand and in process, while on the other the pieces are charged off when required for assembling in machines. The balance at all times shows the number of pieces on hand or in process.

When a machine is to be built, a list of all the parts is usually prepared for use in the shop. If a stock ledger is used, all of the parts kept in this ledger can be checked in at once and charged off on the ledger account. The balance of the material can then be ordered.

It is necessary now to know the cost of material in this series of machines. In some shops the cost of material is found for each individual machine, but when a number of machines exactly alike are built it seems like a waste of energy to repeat this work for each one.

Fig. 461 shows a page from a book devoted to keeping the cost of material in a series of machines. The cost of material in most machines depends principally on a few large items, the rest changing very slightly in cost and not having much effect on the total cost. It is, therefore, the work of but a few minutes to revise this cost book for fluctuating prices and keep it up to date.

In describing all of the foregoing systems to you I have aimed at simplicity, and have, therefore, taken only general cases.

Some of you may from this be led to think that they are limited in their application. This is not so, however, as I could have shown by giving examples of their application in special cases; but as the object of this paper was not to specialize, I have refrained from doing so.

Name.	8½×8	10×10	12×11	14×12	15×14	16×16
Connecting rod box (crank)	$0.40	$0.50	$0.60	$0.75	$0.90	$1.00
Connecting rod box (Xhd.)	.35	.50	.55	.70	.75	.90
Connecting rod babbit shells (crank)	.10	.10	.10	.10	.15	.15
Connecting rod strap, key and block	2.00	2.30	3.25	3.50	4.25	5.25
Counterbalances (2)	.10	.15	.15	.20	.20	.25
Crank shaft	2.75	3.25	3.90	4.50	4.75	5.25
Crosshead and pin	1.20	1.40	1.55	1.75	1.80	2.05
Frame	3.60	3.75	4.25	4.50	4.75	5.00
Guide (lower)	.25	.30	.40	.45	.45	.50
Guides (upper) (2)	.20	.30	.40	.50	.55	.60
Guide pillars (3)	.05	.05	.05	.10	.10	.10
Oil pump (complete)	.15	.20	.20	.20	.20	.20
Pillow block caps (2)	.15	.15	.20	.25	.30	.35
Pillow block gibs (2)	.10	.10	.10	.10	.15	.15
Pillow block babbit liners (2)	.05	.05	.05	.10	.10	.10
Rock shaft bracket (complete)	1.00	1.10	1.10	1.25	1.35	1.50
Rock arms on shaft	.50	.60	.65	.70	.75	.80
Eccentric carrier and bushing	.55	.70	.80	1.00	1.10	1.15
Eccentric rod	.35	.40	.45	.45	.50	.50
Governor weight and bushing	.20	.25	.30	.30	.30	.45
Governor spring	.10	.10	.10	.15	.15	.15
Cylinder	1.40	1.50	1.70	1.80	2.00	2.20
Cylinder head	.30	.45	.45	.60	.60	.75
Cylinder head plate	.20	.20	.25	.25	.30	.35
Cylinder jackets (2 pieces. Set)	.05	.10	.10	.10	.15	.20
False head	.25	.30	.35	.45	.60	.70
Piston and rod	.40	.60	.90	.90	.95	.95
Piston rings (2)	.10	.15	.20	.25	.25	.30
Piston gland	.05	.10	.10	.10	.15	.15
Steam chest cover	.15	.20	.20	.25	.30	.35
Valve	.65	.70	.75	.80	.90	1.00
Balance wheel	1.15	1.25	1.35	1.90	2.00	2.25
Governor wheel	1.40	1.70	1.75	1.90	2.25	2.35
Scraping	1.40	1.60	1.65	1.80	2.00	2.30
Nickel plating	1.00	1.15	1.20	1.40	1.60	1.90
Erecting and testing	9.25	11.00	12.50	13.50	15.00	16.00
Boxing	.60	.75	.75	.90	1.00	1.10
Total labor cost	32.40	38.00	43.35	48.45	53.60	59.25

Fig. 460.—Labor Cost of Simple Engine Parts and Total Labor Cost.

Name of Parts.	8½ × 8				10 × 10				12 × 11				14 × 12				15 × 14				16 × 16.			
	No. Pcs.	Total Weight.	Rate.	Cost.	No. Pcs.	Total Weight	Rate.	Cost.	No. Pcs.	Total Weight.	Rate.	Cost.	No. Pcs.	Total Weight.	Rate.	Cost.	No. Pcs.	Total Weight.	Rate.	Cost.	No. Pcs.	Total Weight.	Rate.	Cost.
Steel.																								
Connecting rod	1	38	6c	$2.28	1	55	6c	$3.30	1	75	6c	$4.50	1	102	6c	$6.12	1	129	6c	$7.74	1	163	6c	$9.78
Connecting rod strap	1	15	2	.30	1	17	2	.34	1	18	2	.36	1	24	2	.48	1	32	2	.64	1	40	2	.80
Connecting rod key	1	1½	5½	.08	1	2½	5½	.14	1	3	5½	.18	1	4	5½	.22	1	4½	5½	.25	1	5	5½	.28
Crank shaft	1	260	6½	17.60	1	372	6½	25.50	1	481	6½	32.40	1	650	6½	48.88	1	925	6½	60.25	1	1160	6½	71.50
Crosshead pin	1	7	3½	.24	1	13	3½	.45	1	17	3½	.59	1	22	3½	.77	1	29	3½	1.02	1	33	3½	1.16
Eccentric rod	1	11	2	.22	1	16	2	.32	1	18	2	.36	1	20	2	.40	1	23	2	.46	1	25	2	.50
Governor spring	1	18 ft. bar 5-16 wire		.22	1	16 ft. bar ⅜ wire		.27	1	16 ft. bar ⅜ wire		.27	1	16 ft. bar ⅜ wire		.37	1	16 ft. bar ⅜ wire		.37	1	16 ft. bar ⅜ wire		.37
Governor weight stud	1	5½	2	.11	1	6	2	.12	1	8	2	.16	1	12½	2	.25	1	12½	2	.25	1	15½	2	.31
Key and set screw wrench	1	1½	10½	.19	1	1½	10½	.19	1	1½	10½	.19	1	2	10½	.21	1	2	10½	.21	1	2	10½	.21
Piston rod	1	11½	3½	.40	1	19½	3½	.68	1	20	3½	.70	1	28½	3½	1.10	1	44	3½	1.54	1	44½	3½	1.56
Rock arm pin	1	4½	5½	.25	1	7	5½	.38	1	7½	5½	.40	1	7½	5½	.42	1	13	5½	.71	1	14	5½	.77
Valve stem	1	2	5½	.11	1	2½	5½	.19	1	3½	5½	.19	1	4	5½	.22	1	6	5½	.33	1	7	5½	.38
Total				$22.00				$31.88				$40.30				$59.44				$73.77				$87.62
Brass.																								
Connecting rod box (Xhd.)	1	8	22	1.76	1	11½	22	2.47	1	14½	22	3.19	1	16½	22	3.63	1	22½	22	4.95	1	27	22	5.94
Crank splasher handle	1	¾	18	.14	1	¾	18	.14	1	¾	18	.14	1	¾	18	.14	1	¾	18	.14	1	¾	18	.14
Eccentric rod head (brass)	1	....	....	2.00	1	....	....	2.00	1	....	....	2.00	1	....	....	2.00	1	....	....	2.50	1	....	....	2.50
Governor link bushings	2	....	20	.40	2	....	20	.40	2	....	20	.40	2	....	30	.60	2	....	30	.60	2	....	30	.60
Governor weight bushing	1	3	18	.54	1	3½	18	.68	1	5½	18	.94	1	6¾	18	1.21	1	6¾	18	1.21	1	8	18	1.44
Oil pump air chamber	1	1	18	.18	1	1	18	.18	1	1	18	.18	1	1	18	.18	1	1	18	.18	1	1	18	.18
Rock arm pin caps	2	....	16	.32	2	....	16	.32	2	....	16	.32	2	....	16	.32	2	....	18½	.37	2	....	18½	.37
Valve stem head	1	....	....	2.00	1	....	....	2.00	1	....	....	2.00	1	....	....	2.00	1	....	....	2.50	1	....	....	2.50
Valve stem stuffing box	1	....	....	1.50	1	....	....	1.73	1	....	....	1.73	1	....	....	1.73	1	....	....	1.73	1	....	....	1.73
Total				$8.84				$9.92				$10.90				$11.81				$14.18				$15.40
Babbit.																								
Connecting rod babbit shell	1	3½	32	1.20	1	4½	32	1.44	1	7	32	2.24	1	8	32	2.56	1	9	32	2.88	1	11	32	3.52
Crosshead babbit	1	12	32	.24	1	1½	32	.40	1	1½	32	.48	1	2½	32	.80	1	2½	32	.88	1	3	32	.96
Eccentric rod head babbit shell	1	10	32	.20	1	1	32	.32	1	1	32	.32	1	1¼	32	.40	1	1½	32	.40	1	1½	32	.40
Pillow block babbit liners	2	10½	32	3.44	2	15	32	4.80	2	22	32	7.04	2	30	32	9.60	2	35	32	11.20	2	42½	32	13.60
Total				$5.08				$6.96				$10.08				$13.36				$15.36				$18.48

Fig. 461.—Cost of Material for Simple Engines.

DISCUSSION.

Mr. William Wallace Christie.—While in charge of the general foundry work of a large iron works I introduced, or rather tried to introduce, systematic records, orders, etc.

When new patterns were to be made, or old ones altered, the order was written on a blank (Fig. 462) which, being printed in copying ink, made the copying of the written order in a letter-press book a complete record of the order.

When the pattern or alteration was completed, the examiner received the blank, and noted all of its data in the copy-book. The use of this blank for about three years proved its value for the class of work then under my charge.

PATERSON, N. J. ..... 190....

PATTERN-MAKER'S ORDER No. .....

Make ..... pattern of .....

as per drawing No. ..... herewith.

Charge time and material to .....

GENERAL NOTES.	MATERIAL AND TIME.		COST.	
	Amount.	Rate.	$	cts.
	Total cost.....			

Pattern work started ..... 190.... Pattern finished ..... 190....

Pattern examined ..... 190....., by ..... and found correctly made.

JOHNSON IRON WORKS,
JOHN JONES, *Asst. Mngr.*

FIG. 462.

Mr. J. Sellers Bancroft.—"Everything pertaining to the construction of the machines must originate in the drafting room," in the second paragraph, is, perhaps, a wrong expression for what the author intends; on all details and many points of design the opinion of the shops is to be sought and followed. The function of the drafting room is that of a bureau of record of

the judgment and conclusions of the practical men who design and who make the machine. It is true that nothing should be done in the shops that is not authorized and recorded by the drawing, but in many cases this is best accomplished by the alteration of the drawing to correspond with the work; that is, the drawing room must never be an obstacle in the way of improvement. Put only one piece on a tracing is an excellent rule; but put all views of the piece, if possible, on the same tracing is as good. All information that can be of service to the shops should be put on the tracing as suggested, and the dimensions for finishing surfaces should be accompanied by symbols indicating the quality of finish as well as the permitted tolerance or deviation from exact sizes, so that the workman may not waste time in trying to obtain a much better fit or finish than is really needed for the particular case, while his attention is especially directed to the close finishes. All drawings when finished should be examined by a mechanical examiner, to determine the method of manufacture and the sequence of operations on the piece; at this time any small changes can be made that will facilitate the work, and the amount of finish and the way the casting is to be moulded can then be determined and recorded.

The method proposed for marking the patterns, especially where they have to be sent to outside foundries, seems to be very comprehensive; in our own practice we have found a decided advantage in using the drawing number from which the pattern was made as part of the symbol of the pattern. This forms a most satisfactory method for identification of the pattern, especially when there have been many changes, owing to alterations in the machine, as no changes are permitted without a drawing to define and authorize them. For repair orders, taken in connection with a well-organized record system, the pattern storekeeper is never at a loss to know which pattern to use to fill a requisition from the drawing room. All that the author has to say about record sheets of standard parts is excellent, but his suggestion of appropriating certain series of numbers in advance for certain diameters or sizes is almost sure to lead to trouble, as it appears to be impossible to foresee the growth of the various classes. If, however, these numbers be considered as decimals, a much finer division of classes can be made, and the initial figures can then indicate certain types, styles, or sizes, and figures may be added indefinitely as occasion

arises, without resort to fractional numbers, and without changing the original order of the parts, as in the well-known Dewey system of classification.

To explain more fully the method of marking patterns above referred to, I subjoin a copy of the plan adopted some fifteen years ago by William Sellers & Co., Incorporated, which also shows how temporary and permanent changes in a pattern are distinguished and recorded, and has proved very successful in taking care of changes for repairs.

WILLIAM SELLERS & CO., INCORPORATED.

NOVEMBER 1, 1886.

SYSTEM OF MARKING PATTERNS.

All pattern lists must contain, in addition to information usually furnished, the numbers of the drawings from which it is intended the various patterns shall be made.

The first column of the list will give the number of castings required, the second the "list number," and the third column the "drawing number," thus:

Pieces.	No.	Drawing No.	Name.
1	1	8080	Saddle.
1	2	8080	Crossgirt.
1	3	8081	Upright.

FIG. 463.

Each pattern when finished must be marked by a suitable label bearing the list and drawing numbers joined by a dash, thus: 1–8080, 2–8080, 3–8081, etc. This is the distinctive mark of the pattern, and must never be altered unless the pattern is changed; and if the pattern be changed, this symbol must indicate the fact.

When any pattern so marked is used in a subsequent machine of any kind, it will appear in the list with its original symbol, thus:

Pieces.	No.	Mark.	Name.
1	1	1–8080	Saddle.
1	2	2–8080	Crossgirt.
1	3	5–7979	Upright.

FIG. 464.

The fact that the original list number appears in the "Mark" column indicates that the pattern has already been made. As written in Fig. 464 it is understood that no alteration is required.

If a permanent alteration is needed, the original drawing number is stricken

out by a horizontal line and a new one substituted below, thus, $\frac{1\text{–}8080}{8082}$. But if a temporary alteration is required and it is intended that the pattern shall afterwards be restored to its original form, the new number is written like the denominator of a fraction, thus, $\frac{1\text{–}8080}{8085}$. The list would then be written :

Pieces.	No.	Mark.	Name.
1	1	$\frac{1\text{–}8080}{8082}$	Saddle.
1	2	$\frac{1\text{–}8080}{8085}$	Crossgirt.

FIG. 465.

This means that piece 2 is made by altering a pattern, No. 1–8080, and therefore all the special parts made for this alteration will be marked 2 $\frac{1\text{–}8080}{8085}$, but the label on the original pattern will be unchanged.

If one pattern can by slight alterations be made to serve for two the list must indicate the fact :

Pieces.	No.	Mark.	Name.
1	3	8080	Right-hand upright.
1	4	3–8080 alt.	Left-hand upright.

FIG. 466.

This indicates that pattern No. 4 is the same as No. 3 just made except that certain minor parts are altered. Those parts of the pattern which are common to both 3 and 4 are so marked, *i.e.* (3 and 4–8080), while the special parts are either 3–8080 or 4–8080.

Gear patterns for cast teeth must bear the proper gear symbol, and the absence of the symbol will indicate that the wheel is to have cut teeth. Thus a new list might read :

Pieces.	No.	Mark.	Name.
2	1	8282	Mitre wheel, 12′ 4 per inch.
3	2	$\frac{12013}{8282}$	Spur wheel, 13′ 1½ inches pitch.

FIG. 467.

This shows that No. 1 is a cut wheel and that No. 2 is made from the pattern of spur wheel 13′ 1½ inches pitch altered as per Dr. 8282, and a reference to the gear list will show whether or not this pattern has been already made. The absence of the list number in the mark column indicates that the numerator of the fraction is a gear number and not a drawing number.

A white label with the pattern mark should be placed on each part of every

arises, without resort to fractional numbers, and without changing the original order of the parts, as in the well-known Dewey system of classification.

To explain more fully the method of marking patterns above referred to, I subjoin a copy of the plan adopted some fifteen years ago by William Sellers & Co., Incorporated, which also shows how temporary and permanent changes in a pattern are distinguished and recorded, and has proved very successful in taking care of changes for repairs.

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A white label with the pattern mark should be placed on each part of every

pattern, and the label on the principal part should be marked with the number of pieces of which the pattern consists. Each piece of pattern should also bear a red label giving the location of the pattern; that is, a description of the place in which it is to be stored. This must be written in the following order: 1. Department; 2. Section; 3. Shelf; 4. Division; and 5. Box, if one be used. If written in the proper order, the names of the department, etc., may be omitted, thus: 1 F, 12, 5, 14 would be understood at once.

In storing patterns, parts made to adapt an existing pattern to a new use must be stored with the other patterns made on the same order and the original pattern or basis of the alteration must be separated from the alterations and returned to its proper place. For example, in a box of patterns might be found some pieces marked $5\frac{2\text{–}8080}{8184}$; from this it is known that these parts are to be used with a pattern marked 2–8080, and the question is where to look for that pattern. A reference to a List of Drawing Numbers and Titles shows that 8080 represents, say, the crosshead of a 132-inch Boring Mill, and is dated January 1, 1886; we therefore seek the pattern in question among the patterns of the 132-inch Boring Mill.

If, for any reason, the pattern maker shall deem it necessary or desirable to change the symbol on any pattern, he must at once notify the drawing room by a written memorandum, so that the pattern lists may be corrected. It is of the utmost importance that the pattern mark shall correspond with the drawing-room record.

Prof. Charles L. Griffin.—The paper under discussion deals with a very important subject of modern economical manufacture. It is, however, absolutely impossible to lay down a general set of rules which shall be anywhere near universal, and it is doubtless in recognition of this fact that Mr. Ball opens his paper with a moderately qualified statement. It seems to me, however, that as far as the drawing-room practice is concerned, he takes a very one-sided view of the case, and would convey the idea that the points he makes are almost axiomatic, and all other systems could well be corollaries to the one he presents. This, to my mind, is far from the truth.

In the first place, the rights of the drawing room are not on a plane with the ancient divine rights of kings, in that it can do no wrong. To be frank, I do not think he means quite that, but his statement pretty nearly says so. The drawing room is, after all, but one of the several important departments of a concern, and constitutes the great recorder and index to all the product of the shop. It should, however, be autocratic only to the extent of such, and thus invariably place responsibility where it belongs. Much may originate outside of the drawing room which the latter may not wholly judge, but which it assuredly should record. The arbitrary control should rest with the super-

intendent, not with the drawing room; but that information of shop construction should always be available through the drawing files is, of course, essential.

The three rules for the production of tracings given in this paper it is impossible for me to conceive as being of at all general application.

With regard to the first rule, to put only one piece on a tracing, the objections raised to the general method of many pieces on one tracing are not well founded. It is not true that if any one part be changed it is necessary to retrace the whole sheet, and so far as I know it is never done. Proper order sheets, specifying what parts to use from each sheet, will easily take care of this during construction, and an equivalent record preserved in this or other form provides for subsequent reference.

If the second objection raised by Mr. Ball, that having more than one part on a sheet would necessitate more than one print in the shop, be carried to its legitimate conclusion, it would mean that every part on the sheet would be in process of construction simultaneously, and hence there should be as many blue prints as there are parts. This is inevitable by his own system of single-piece tracings, only his prints would be smaller. Hence the objection is only one of degree if the case stood thus. But pieces do not go through the shop in this simultaneous fashion, and even though there be a dozen or more pieces on a single sheet, with the ordinary shop progression I have found that a couple of prints satisfy every demand. Two moderate-size prints are manifestly more convenient than a dozen, no matter how small the latter may be. I once worked in a shop where the single-piece drawing was tried, and the system was not maintained for, to me, very obvious reasons.

The objection that reproduction of tracings is liable to cause error is certainly true, but again such a simple device as order sheets at once gets over the difficulty, for reproduction only becomes necessary for the parts which are changed; this is exactly the same amount of reproduction which has to be done in the single-drawing system, hence I see no advantage here.

With regard to the next objection, I would say that I never have seen anybody do the amount of retracing and reprinting which Mr. Ball implies has to be done in order to keep track of changes, if the usual method of grouping details on a single drawing is followed. It seems to me unnecessary to go into the

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detail of the numberless ways in which all difficulty can be avoided. In my own personal experience, covering a somewhat varied line of work in different shops, under different grouped systems, and on both standard and special construction, I have never found any particular difficulty either in conforming to the system already in use, or satisfactorily modifying or originating details of it if necessary.

The second rule, with regard to placing different views of the same piece on different sheets, is one which, to my mind, has no advantage worth mentioning and might lead to serious trouble. It is certainly inconvenient for the workman, and allows him to arrange the views, perhaps wrongly, with reference to each other. The advantage of working duplicate pieces on different processes at the same time would seem to me to be of little moment, seldom occurring, and when desired, entirely met by a duplicate print. The size of the print is no bugbear, for it has no right to be a "large" print anyway.

The third rule is a good one concerning the size of the prints, but as to scale, I should say, in general, use as large a scale as is consistent with the standard shop size of sheet. It seems to me the important thing to settle, once for all, is a convenient standard size of sheet for shop details, then stick to that size, and make the scale to suit. In very rare cases, such as general or special drawings, a larger size may be allowable. The disadvantage of having even two different sizes of prints to handle in the shop more than offsets any momentary inconvenience to the draftsman. I have found that once the rule is made and understood to be inflexible, it is not at all difficult for the draftsman to conform to the requirement and do equally good work. I am in full sympathy with Mr. Ball concerning "bed-quilt" drawings, although our marine engineering brethren seem to be unable to avoid them.

Instruction to the pattern maker as to the amount of finish to be allowed on each and every surface, as suggested in this paper, should be cautiously given. Contrary to the idea advanced, a good pattern maker, in my opinion, is more closely related to the foundry than is even a good draughtsman, and is therefore in a better position to determine the amount of finish under ordinary circumstances. It seems to me that preferably the pattern maker should be held responsible for warped or bulged castings, or excessive or deficient finish. It is his business to make proper

patterns, and though the drawing room may influence him by consultation and suggestion, yet to make the draughtsman responsible for proper finish on patterns is to add still another load to an already mountainous burden of responsibility, and is of no avail. If castings do not come right, it is the business of the pattern maker to hustle round and discover it long before the drawing room does, and plan to correct the trouble. It is the trick of his trade to make patterns which will produce castings to drawings.

Mr. Ball, of course, realizes the special requirements of his business much better than I do. My idea is that a good organizer will work out a system which will enable him to handle his work to advantage. I believe, however, that his paper tends to advocate a more general application of his principles than is possible. In fact, I believe there are very few shops in which these principles can be economically maintained.

Mr. Knox.—There have been a great many papers on systems described for making drawings, and nearly every time the criticism is such as has been made of this, that it has only local application.

It might be interesting to know how this system would fit the work of the drafting room of the General Electric Company. There would be at least 10,000, and perhaps 15,000, separate drawings and 300,000 blue prints each month. They would be rather difficult to handle. We have 260 draftsmen, and if they had to make a separate drawing for each piece, or rather two or three different sheets in order to show one piece, it would be impossible to handle the work. There is a more general system, drawing a line between the two extremes represented by the systems described and the primitive one with which nearly all shops start when there is just as little system as possible. I never before heard of such refinements as are here suggested, such as several sheets to one piece. The question of keeping related drawings together is certainly worthy of some consideration, but would be extremely difficult under this system.

The intermediate system referred to is one which puts related parts on one sheet, perhaps a dozen or fifteen pieces that properly may go together, and the ability to see which, as put together, would be an aid to the workman. We may want to use some of these pieces in new apparatus, and yet do not want to do the work over again. The least objection is the cost of

redrawing: one great objection is the fact that if you draw the same piece on several different sheets, if it is a thing which can be made with special tools, somebody six months or a year later will make some alterations in one of those drawings, but not in all the places where it is recorded, and the tools will be changed to agree; then when you want to use the piece as originally shown, you find you have not the tools with which to make it. The method by which any number of pieces can be drawn on a sheet and yet no redrawing of the same piece called for is known as the group system.

Here are a lot of pieces on a sheet, which I will call 1, 2, 3, 4, and 5. At some places it is usual simply to draw those pieces and give them numbers, the specification of material, number of pieces wanted, etc., being on a separate specification sheet. That system works, but it has objections. Some changes can be made and noted simply on the bill of material; the drawing is apt to be left unchanged, while the bill of material is changed. Now it is highly desirable to concentrate all information necessary for the manufacture of any piece right on the sheet upon which it is drawn. So there are put down the pattern number, material, and name of each of the parts shown on the sheet. There are also put opposite each part number the number of pieces of that part needed in making the unit for which the drawing is prepared. Let us assume that later we want to make a small change in that unit. Then comes in what is known as the group system. We find specified in the title a number of parts. We want three pieces of part 1, four pieces of part 3, seven of part 6, etc. We bunch those things and call them a group. Let us call that group No. 2 of drawing No. 999. Now if we want to make up something else—using six pieces of part No. 1, five of part No. 2, etc.—we simply write out another group, which we will call group No. 3, etc.

When you want a new device, you simply say on your instructions to the shop, "Make this job from drawing No. 999, group 2; drawing No. 11, group 3, etc.," and the workman takes up his drawing and finds the particular group number that he wants, and in that way he finds which of the pieces shown on the sheet and how many of each piece are to be made. A space is reserved at one side of the title in which any changes are noted. For instance, if part No. 3 is changed, we would say that part 3 had been changed on a certain date, and note the

nature of the change. Then in looking that drawing up subsequently as a matter of history, wanting to know what had been used at a certain time, we would see what materials were used, and the date when the change, if any, was made, and so the drawing is kept as a live shop drawing and also as a permanent record of everything that has been done. We find this very useful and satisfactory in the drafting room that I refer to, where men come and go, and where we have about 100,000 drawings.

The key to this system is the drawing list. The drawing list for each job is usually contained on one 8-inch by 10½-inch sheet. If we had one piece per drawing it would necessitate our having a drawing list on the average job which would be ten times as long as our present list. That is one advantage of having comparatively few drawings and several pieces on a sheet. Our drawing list tells the name of the principal parts and the drawings on which they are to be found. So in a machine that has, perhaps, 200 parts we send out a drawing list that contains probably 20 items.

Mr. Howard Wells Smith.—This very excellent paper has been of great help to me, and I am sure to everybody ; but there is one point which seems a little strange, and that is that the author makes no mention of the use of cards for indexing and recording. He speaks of a pattern record book, and blue-print record book, etc., whereas if cards were used the whole record would be in much neater shape. The idea of putting one piece on a sheet is, to my mind, not very good, for I have tried both ways. It may work out in special cases, but in most instances I have found that more than one piece had better be put on a sheet.

In regard to this group system, or scheme, which Mr. Knox has illustrated on the blackboard, it seems as if that grouping might in time require the whole space on the sheet; otherwise I believe it is a very good scheme.

Mr. Elmer H. Neff.—The paper presented by Mr. Ball and the discussion of it simply illustrate the fact that a great many systems are necessary in order to run satisfactorily a large variety of shops. Our drawings are made on bond paper and inked in so that there are few, if any, tracings ever made. Blue prints are made from the bond-paper drawings, and form the permanent record for each machine we have built, these blue prints being kept in vaults after they have passed through the

shop. When the blue prints are sent into the shops, they are mounted on boards bound with cloth along the edges and with a moulding around the board on the side which carries the drawing, so that when the board is laid face down it will not allow the blue print to touch the object on which it is placed. Our bond-paper drawings are kept in drawers and form the latest record of the patterns and machines. They are constantly subjected to changes and cancellations of the various parts shown on them, all those pieces being eliminated which are not required for the particular machine being made. We put as many pieces on the sheet as possible, but do not mix up different kinds of work. The varieties of work are separated on the sheets according as they are lathe work, planer work, screw-machine work, forgings. Our drawings are indexed in a very thorough manner in the card index system, and are in charge of a man who is familiar with them. The main feature of our plan is that *blue prints* and *not drawings* are the permanent record.

*Mr. F. O. Ball.**—In reviewing the discussion of this paper, several of those who participated overlooked the opening paragraph, in which it was stated that the systems to be explained were not expected to cover all cases.

Mr. Bancroft's interpretation of the second paragraph is practically what was intended, as the drafting room and engineering department are supposed to be one. His suggestion, "The finish marks should be accompanied by symbols indicating the quality of finish," etc., is an excellent one.

The group system as explained by Mr. Knox seems to be very comprehensive, and no doubt operates very successfully. This is not inconsistent with the rules laid down, as two of the three rules are declared to be "somewhat elastic." A modification of the group system, which would be consistent with Rule 1, and would meet the objection of Mr. Knox to the length of the "drawing list," is as follows: Detail the several parts off on separate small drawings (as much as is considered necessary), and then on another tracing group the different parts as suggested by Mr. Knox.

It is not quite apparent from his discussion how he can describe these groups on the drawing list if the group includes several parts with different names.

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* Author's closure, under the Rules.

No. 910.*

RULES FOR A DRAWING OFFICE.†

BY A. W. ROBINSON, MONTREAL, CANADA.
(Member of the Society.)

In June, 1894, the writer presented a paper to the Society entitled, "On the Relation of the Drawing Office to the Shop in Manufacturing," in which was given a set of rules which he then used in the drawing office under his charge. As improvement is always the order of the day, it became advisable to revise these rules, as suggested by experience, making them more concise and covering additional points as they arose. These revised rules are given below in the hope that they may prove useful.

Drawing Office Rules.

Size of Drawings.

1. The standard size shall be 23 inches by 36 inches, subdivided into half, quarter, and eighth sheets.

2. Full size drawings shall be reserved, as far as possible, for general views, and parts not capable of being shown on smaller sheets.

3. All shop detail shall, as far as possible, be shown on quarter and eighth sheets.

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* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† For previous discussions on this subject consult *Transactions* as follows:

No. 48, vol. ii., p. 369: "Method of Arranging and Indexing Drawings and Patterns." A. F. Hall.

No. 56, vol. ii., p. 576: "New Method of Keeping Mechanical Drawings." C. J. Porter.

No. 143, vol. v., p. 193: "Drawing Office System." H. R. Towne.

No. 596, vol. xv., p. 596: "Relation of the Drawing Office to the Shop in Manufacturing." A. W. Robinson.

No. 614, vol. xvi., p. 106: "Drawing Office Appliances." A. W. Robinson.

No. 909, vol. xxii., p. 1040: "Drafting-room and Shop System." F. O. Ball.

Character of Drawings.

4. Detail drawings shall, as far as possible, classify the different kinds of works, such as castings, forgings, shafts, levers, piping, etc. Different kinds of work shall not be shown on the same detail drawing.

5. All shop drawings liable to repetition shall be traced and blue-printed. All temporary details, requiring only one copy, may be made on sketch sheets and press-copied.

6. A shop drawing is to be considered as an order or instruction to the shop, and not merely as a statement or illustration. For this purpose it must convey clearly and distinctly all the information necessary to make the article.

7. Every dimension necessary to the execution of the work is to be clearly stated by figures on the drawing, so that no measurements need to be taken in the shop by scale. All measurements to be given with reference to the base or starting point from which the work should be laid out, and also with reference to centre lines.

8. All figured dimensions on drawings to be plain round vertical figures, not less than $\frac{1}{8}$-inch high, and formed by a line of uniform width and sufficiently heavy to insure printing well. No thin, sloping, or doubtful figures or diagonal-barred fractions will be tolerated. All figured dimensions below 2 feet to be expressed in inches.

9. All centre lines to be alternate dot and dash in fine black line. All dimension lines to be double dot and dash, with a central space for the figure, and of such strength as to show on blue-print more faintly than lines of drawing. Lines of drawing to be bold and clearly defined in proportion to the scale, and may be shade-lined by making the right-hand and bottom lines heavier. No ornamental shading or other "frills" allowed on shop drawings.

10. Every drawing, whether whole or half-sheet, shall have the title, date, scale, and number of the sheet stamped in lower right-hand corner, and the quarter and eighth sheets printed on top.

11. The name of the drawing, as given in the title, is invariably to consist of two divisions in one line separated by a hyphen. The first division is to state the general name of the thing or machine, and the second name is to clearly designate

the part or parts represented (or if a general view should so state). The wording of titles should be submitted to the chief engineer or head draftsman for approval.

12. Each drawing shall bear the name of the draftsman and examiner, the surname being used without initials.

13. Drawings of piping details shall be made in diagram form, using standard symbols.

14. All detail parts for standard or repetition work shall be shown unassembled as far as possible.

Drawing Symbols.

15. Detail shop drawings should state :

(*a*) The pattern number of every casting in plain figures of larger size than the dimension figures.

(*b*) The material of which the parts are made, using symbols as follows :

C.I.—Cast Iron.	Bs.—Brass.
W.I.—Wrought Iron.	Bbt.—Babbitt.
M.S.—Machinery Steel.	Bz.—Bronze.
H.S.—Hammered Steel.	C.R.S.—Cold Rolled Steel.

Other materials write full name.

(*c*) Finished surfaces will be indicated by "f" written on the line or surface to be finished. When not so marked it is understood that the part is to be left black or rough. In cases where finish might be presumed but not required, follow the figured dimensions by the word "Cast," if a casting, and "Rough," if a forging.

Standards.

16. The following standards shall be strictly adhered to as given in the tables noted :

1. Table of standard diameters of shafting and key seats.
2. Table of standard stock sizes of rounds.
3. Table of standard stock sizes of flat steel.
4. Table of standard clearance fits.
5. Table of standard symbols for notation of riveting.
6. Table of standard symbols for pipe fittings.

Also such other standards as may be adopted from time to time.

Numbering of Drawings.

17. Drawers and filing cases shall be numbered consecutively. Drawers shall contain 100 sheets each, and filing cases 200 sheets each, and to be fully indexed. Drawings shall be numbered by a number indicating both drawer number and serial number in the drawer, thus: 76-4 is the fourth sheet in drawer 76, etc.

18. Drawing numbers shall be checked off the index as required, and the index posted up in uniform handwriting by the clerk.

19. Standard size drawings shall be kept in drawers and quarter and eighth sheets in filing cases. All drawings shall be indexed by an index sheet kept in each drawer or case.

Checking.

20. All drawings must be approved before being traced. When tracing is completed it will be given immediately to the chief draftsman, who will have a preliminary print made and carefully checked, before being used.

Patterns.

21. All patterns shall bear the number of the drawing on which they are first detailed, followed by a serial letter according to the number of patterns on the drawing.

22. Standard patterns used repeatedly and liable to be ordered from in repairs must not be changed. Other patterns may only be changed when absolutely necessary and by order. When so changed they will bear the original number and letter followed by A for the first change, B for the second change, and so on, thus: 4860 AB is the second change in pattern 4860 A.

Sketch Books.

23. Each draftsman will be supplied with a sketch-book by the company, in which he shall make all his notes, calculations, and data referring to his work, and under no circumstances shall notes of value be made on loose sheets. Each entry should invariably be commenced with the subject and date, and full notes made of data on which the calculations were based, and the results obtained clearly stated. These books are to remain the property of the company.

In General.

24. **Changes in drawings,** sketches, or order lists issued to the shop shall only be made when authorized by the chief engineer, or, in his absence, by the chief draftsman, and when so authorized shall be made by the order clerk.

25. **The names of all similar parts in order lists and drawings are to be uniform.**

26. **Tracing must be kept** in safe for blue-printing purposes only. Office copies of blue-prints must be used for references.

27. **No drawing, print, or photograph shall be taken from office without permission.** Violation of this rule may result in dismissal.

28. **Until further notice the office hours will be from 8 to 12 and from 1 to 5.30. Draftsmen will be paid by the hour for time actually worked.**

29. **Draftsmen who have been in continuous employment of the company for a year or more will be entitled to ten days' vacation, with full pay. No other allowance for time lost will be allowed.**

30. **Draftsmen will not be permitted under any circumstances to write letters in the company's name or on the company's letter-heads or envelopes.**

It will be noticed that rules 2 and 3 provide for the restriction of the use of large drawings to general views, and increased use of small drawings for details. Formerly it was the custom to use only one size of sheet (23 inches × 36 inches) for all purposes. As time went on the multiplication of drawings made it difficult to provide house-room and drawer accommodation, and furthermore the large drawings were not so convenient in the shop as small ones. Resort was therefore had to eighth and quarter sheets, which were indexed in filing cases. This method results in a great number of small drawings, but numbers are cheap and the filing cases are easy to store on shelves, like books, and are practically self-indexing. An index card is placed in the front of each filing case, with lines numbered from 1 to 200, and, as fast as drawings are put into it, the numbers are checked off and the title written in. The ordinary Amberg transfer case is used. Forty of these filing cases do not take up much room,

and they hold 8,000 drawings, part of which are 9 inches × 11½ inches, and part 11½ inches × 18 inches. All these tracings have the company name and title printed in blank with space for date, number, examiner's name, etc., so that uniformity is preserved.

NOTE.—This paper was discussed in connection with No. 909, by Mr. F. O. Ball, which see, vol. xxii., p. 1040.

No. 911.*

THE BARDWELL VOTOMETER.

BY A. FRANCIS BARDWELL, C.E.;
and
BY JAMES HAMILTON, BOSTON, MASS.,
Member of the Society.

THE present activity of mechanical inventive genius and its responsiveness to public wants is strikingly illustrated in the voting machine. To the legislature of a sparsely settled community far from the centres of social progress—to that of South Australia (1857–58), is due the credit of originating the Australian ballot system, which has in the last half-century been so generally adopted among civilized nations; but the credit of devising reliable mechanism which embodies every good feature of the Australian ballot system and at the same time obviates its many serious defects belongs to the American inventor.

Compared with former systems, the Australian system possesses two paramount features:

First: The state controls the printing and distribution of the ballots. Only ballots issued under official sanction can be counted. Again, a nomination made by the few has equal place with that made by the many. Nominations can be made by all and a place on the ballot is open to all.

Second: The arrangement of the polling booth and the rules for marking the ballot are designed to secure compulsory secrecy of voting.

The technical legal requirements of the Australian system have proved a prolific source of litigation and the judicial decisions thereunder have resulted in the disfranchisement of the honest voter. "Perhaps it may be said," remarks one judge, "that protection can be afforded only by imposing a disability." The defective ballots may be classified as follows: (1) Those invalidated by some act of commission or omission on the part of the officials; (2) those invalidated by some act of commis-

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

sion or omission on the part of the voter; and (3) those invalidated by dishonest election officers.

Under the first class may be put cases in which the election officers fail to indorse the ballot as required; cases in which the election officers have marked the ballot erroneously; and cases in which the ballots have not been properly printed or numbered. In regard to the second class of defective ballots, those defective because of failure on the part of the voter himself to comply with the requirements, it may be said that almost every conceivable mark which a voter could make has been the subject of judicial decision. The voters have neglected to make such marks as would indicate their intent; have used the wrong kind of marks; have made conflicting marks; have made distinguishing marks; and have marked with a wrong instrument or in a wrong place. The third class of defective ballots is due to the ease with which a valid ballot may be invalidated by a dishonest election officer without danger of detection. A cross surreptitiously added after the name of the rival of the candidate for whom the elector voted invalidates the vote for that candidate. The Australian system, while hindering "ballot box stuffing" by putting the printing of ballots under state control, gives the dishonest official an easy means of showing a majority of *valid* ballots for his candidate by enabling him through its technical requirements to invalidate the ballots cast for the rival. He may be unable to increase the number of effective ballots cast for his candidate by "ballot box stuffing," but he can decrease the number of effective ballots cast for the rival; and the latter method has the advantage of creating less suspicion. The check-list and the number of ballots cast agree more closely. An inquiry into what the voter did or intended cannot be made. Protection to the secrecy of the ballot requires under this system the imposition of the penalty—the rejection of the ballot.

The system of voting embodied in the Bardwell votometer contemplates the preparation and distribution of the ballot under the control of the state as in the Australian system, and the same freedom of nomination prevails. But the mode of use of the ballot in the two systems differs. In the votometer system only one ballot is printed for each votometer and that is secured upon the face of the machine in such a manner as to indicate to the elector where he may register his vote. No requirements for its technical marking by the election officer or

the voter are prescribed, since the reasons for such marking are absent in the votometer sysem. No opportunity exists, therefore, for unintentionally or intentionally invalidating the ballot, and so none for the disfranchisement of the voter. The votometer, when properly placed in the polling place, secures secrecy as effectually as does the polling booth of the Australian system. It may be readily so placed as to screen the voter from view; and the mechanism being practically noiseless in operation, it is impossible to tell whether the elector has voted or not.

In the means taken to secure secrecy of voting, and thereby freedom of choice and an honest ballot, the votometer system far excels the Australian system. The latter system requires the voter to leave a mark in a designated place, and upon the presumption that there is nothing distinguishing about the simple mark prescribed, bases its claim that secrecy is secured. This presumption may have some foundation in so far as the honest voter is concerned; for, that a voter will unconsciously individualize his cross-mark is not probable. But the presumption utterly fails in the case of the dishonest voter. He may make his cross-mark so that it will meet the requirements of the law and yet make it distinctive enough in form or place to prove by it that he has kept his bargain, "delivered his goods." And his skill is in a measure aided by the liberal rule adopted by courts that the construction shall be against disfranchisement, if such construction can be given without violating some rule of law or sound policy. The Australian system may secure secrecy to the honest voter; but it cannot compel secrecy from the dishonest one.

In the votometer system the voter is not permitted to leave any permanent indices of the choice he has made. No trace of his individual manipulations is visible to others either during or after his operation of the votometer. The machine itself is so arranged as to screen the voter from view; the dials of the registers are hidden within the machine casing; and the indicators which show the *voter* that the register has operated are drawn out of view of his successor by the resetting mechanism operated by the voter as he passes through the exit. The votometer presents, therefore, precisely the same appearance to all voters when they first enter. The votometer secures secrecy to the honest voter and compels secrecy from the dishonest voter.

The fact that in the votometer system the voter is not required or permitted to leave any permanent indices of his choice relieves the election officers and the courts from the necessity of passing upon perplexing questions of validity; obviates the delays and uncertainties attending contested elections; takes away from the dishonest election officer the opportunity of invalidating ballots; and removes from the honest voter the danger of self-disfranchisement. The careless, the stupid, the illiterate voter finds himself restricted to a legal ballot, not by mere force of a statute but by what is infinitely more effective in such cases, the actual physical restraint imposed by the mechanism. The difference is that between "shall not" and "can not."

In the votometer system the mechanical registration of the votes insures an honest and accurate count; relieves the election officers of the tedious work of counting and the perplexing task of deciding; permits despatch in reporting the returns; and renders unnecessary the recounts so commonly called for under the Australian system. Uncertainty gives place to certainty, and delay to promptness.

Description of the Votometer.

The Bardwell Votometer is constructed wholly of steel, brass, and aluminum. The mechanism is enclosed within a metallic casing supported at a convenient height (see Figs. 468 and 469). The back of the casing is removable, made up of two parts hinged together, and secured in place by several locks having different keys. This construction of the back permits the election officers to obtain access to the card-boxes to replenish the supply of cards for the independent vote without exposing the dials of the registers. The different keys are distributed among the election officers so that it requires the consent of all to open the votometer.

The votometer is sectional in construction, which permits interchangeability, gives elasticity of arrangement, and furnishes a means of increasing the capacity of the votometer for special purposes. The standard section is one designed and adapted to register the vote for offices to which only one candidate is elected; such as the office of governor, mayor, etc. The law forbids the elector to cast more than one vote for such an office and the section must be so constructed as to limit him to one vote therefor.

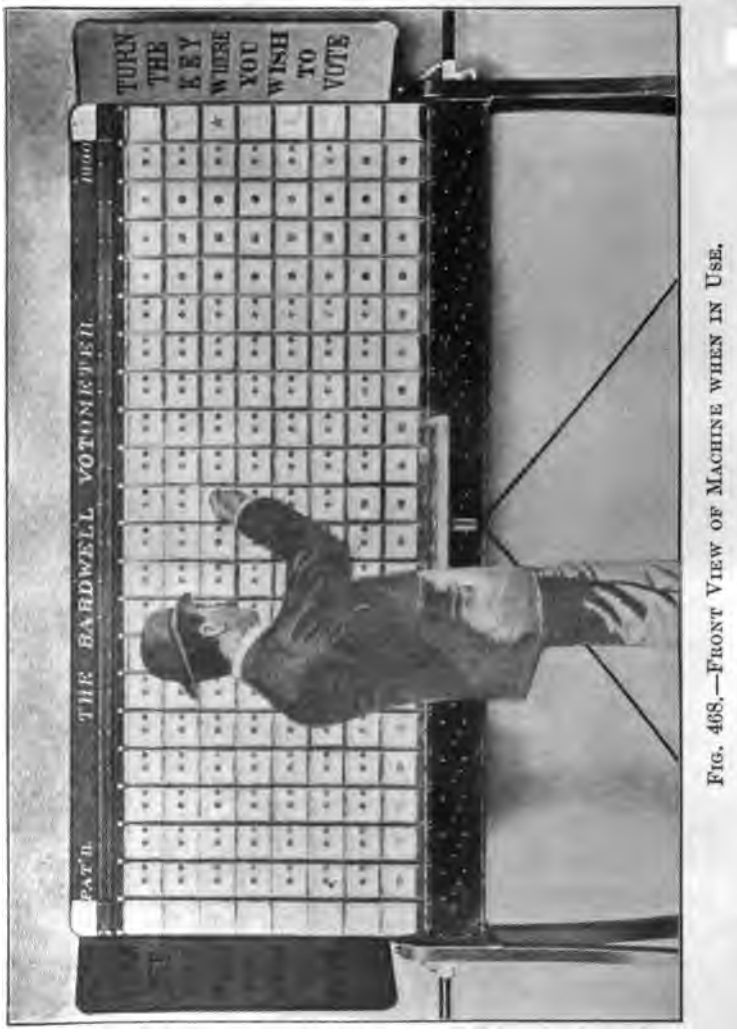

FIG. 468.—FRONT VIEW OF MACHINE WHEN IN USE.

A standard section comprises (see Figs. 470–472, the latter figure being a central longitudinal sectional view with the front casing b^{15} in place) a main plate b of metal, twenty-seven inches long, three inches wide, and three thirty-seconds of an inch thick. Upon the front of this plate are secured the indicators i (Fig. 473), which show where the key has been turned and the register operated, and a portion of the front casing b^{15} (Figs. 472 and 473), which bears upon it the part of the ballot to which the section

FIG. 469.—BACK VIEW OF VOTOMETER WHEN IN USE.

is assigned. The main plate b is secured at its upper end to a hollow steel bar P and at its lower end to a metal base plate P^1 that extend transversely in the interior of the casing (Figs. 470, 471, and 474). On the back of the main plate are secured the registers C, of which there is one for each position on the ballot; and, also, the parts that limit the number of successive times the voter may turn the key in the same direction in that section, those that operate the indicator i above referred to, and those that reset the mechanism after operation. At the upper end of the main plate is attached the card-delivering mechanism, and the card box K, which contains a supply of cards k for the "Independent" vote. A notched vertical slide b^9 ex-

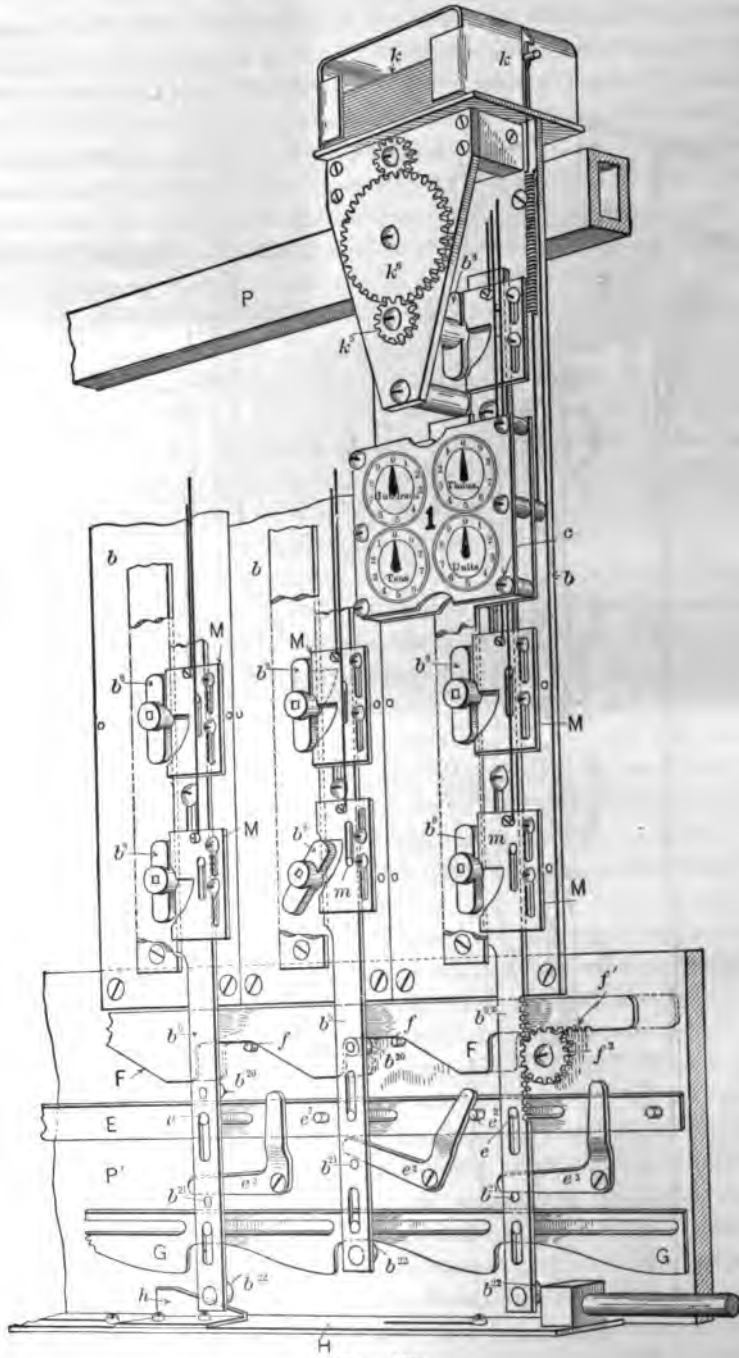
k
k
P
k^5
b^4
k^5
Dollars
Tens
Cents
Units
1
c
b
b
b
M
M
M
M
M
b^3
b^3
b^3
b^3
b^3
m
m
f'
f
f
F
F
f^3
b^{20}
b^{20}
E
P'
G
G
b^{22}
b^{22}
b^{22}
h
H

FIG. 470.

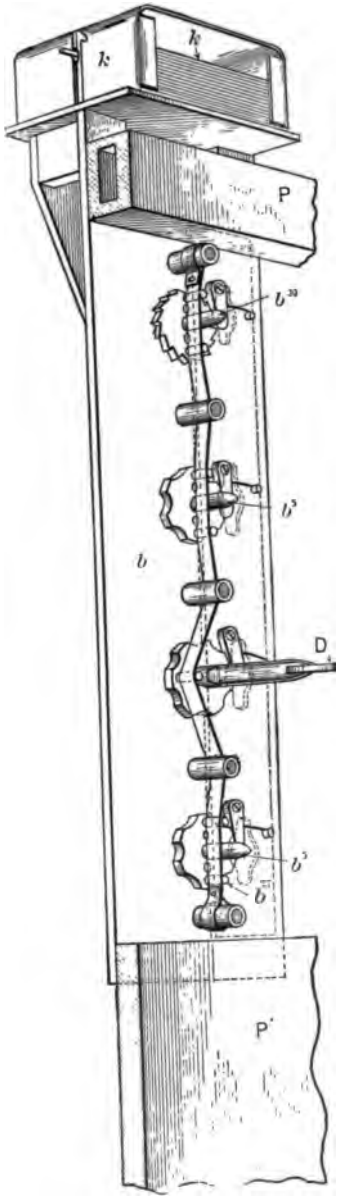

FIG. 471.

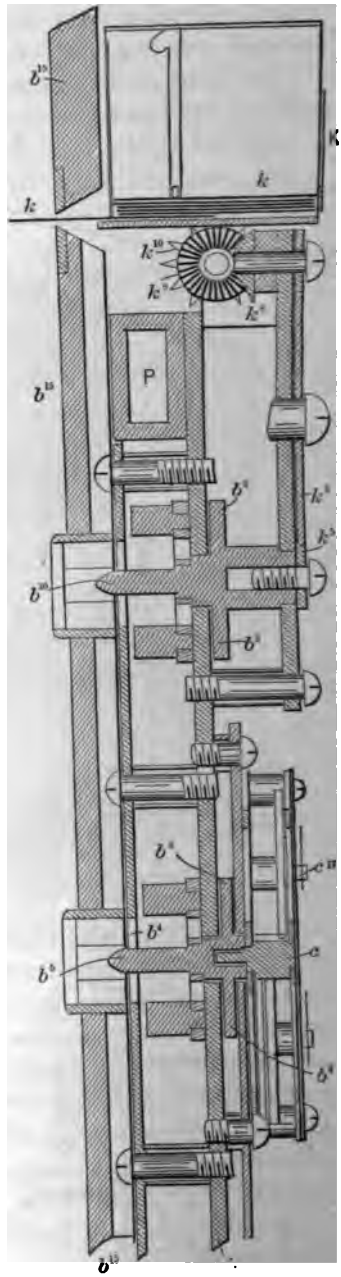

FIG. 472.

tends the entire length of the back of the main plate b (Figs. 470, 471, and 474) and projects below it across the face of the base plate P^1 (Figs. 476 and 477). This slide b^9 is provided with studs b^{20}, b^{21}, and b^{22}, adapted to engage the interlocking slide F, the bell crank e^3, and the main resetting slide G, all of which are secured to the base plate P^1, as shown in Figs. 470 and 475–477. Over each notched portion of the vertical slide and adjacent to each register is a notched indicator-plate M, so called because to it is secured the indicator i (Fig. 473), above referred to. The vertical slide b^9 is free to slide under the indicator-plates i. Through the main plate b extends the shank of a + shaped key-piece b^5 (Figs. 470–472), the outer end of the shank being adapted to receive a key D (Fig. 471), by means of which it is rotated, and the cross piece of the + lying parallel to the back of the plate and forming wings or ears b^8 (Figs. 470 and 472), one of which engages, when the key-piece is rotated, a notch in the adjacent indicator-plate M and vertical slide b^9. A key-piece b^5 is provided for each register C, and one, b^{30}, for the card delivery K (Figs. 470–472), and through a pinion mounted on its inner end serves by its rotation to actuate the register (or card delivery).

The operation of the mechanism which limits the voter to a legal ballot will now be understood. When the key-piece b^5 is turned clockwise by means of the key D (Fig. 471 and the central section in Fig. 470) the lower ear b^8 engages in the notch in the indicator-plate M and vertical slide b^9, the notches in the plate and the slide registering or coinciding (see outer sections, Fig. 470). The engagement of the ear b^8 causes the vertical slide b^9 and the indicator-plate M to rise as the key-piece b^5 is turned, the notches in the vertical slide and the indicator-plate adjacent to the key-piece that is turned remaining in register or coincidence. But as the vertical slide b^9 rises, it slides under the indicator-plates adjacent to the other key-pieces, those that are *not* turned, and the notch in the vertical slide moves out of register with the notch in the said indicator-plates. This is best shown by the dotted lines in Fig. 480 and the central section of Fig. 470. The result is that a projecting portion of the vertical slide (a portion intervening between two successive notches) comes under the notch in the overlying indicator-plate and prevents the inward movement of the lower ear of the key-piece adjacent thereto, while a portion of the indicator-plate covers the notch in the vertical slide and prevents the inward movement of the

upper ear of said key-piece. Therefore, after turning a key-piece clockwise in a standard section it is impossible to turn any other key-piece in that section. Furthermore, it is impossible to turn the same key-piece in the same direction more than a half-turn, as will be made evident by a glance at the lower key-piece in the central section of Fig. 470; hence the elector is limited to one vote on that register, or for his candidate. But since the notches in the vertical slide and the indicator-plate adjacent to the key-piece which has been turned remain in register, the upper ear of that particular key-piece may be turned inward;

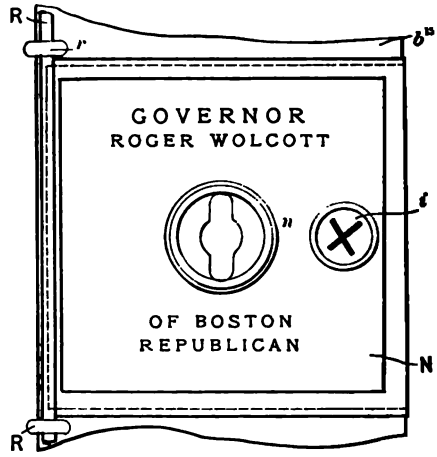

Fig. 473.

that is, the key-piece may be turned in the opposite or counter-clockwise direction so as to count off the vote. The parts will then be restored to their original position shown in the left-hand section of Fig. 470. From this figure it is evident also that the key-piece may be turned backward through only the same arc that it has been turned forward, *i.e.*, a half-turn. From this it results that a voter cannot turn a key-piece backward until he has turned it forward; and while he may correct any mistake, he cannot count off any vote other than his own. The upward movement of the indicator-plate *M* brings into view the indicator *i* attached thereto, which shows the voter that the register has operated, and enables him to verify or correct his vote.

This correction of mistakes is, however, permissible only in case the voter has actuated a *register*. Where the voter, desiring

to cast an independent vote (that is, to vote for one whose name is not on the official ballot), has drawn a card by actuating the card-delivering mechanism, it would be wrong to permit him to turn back the key-piece which he has actuated, and thereby restore the mechanism to its initial position, since this would permit him to vote more than once. To obviate such a result the shank of the key-piece b^{20} of the card-delivering mechanism is fitted with a ratchet b^{12} which engages a pawl b^{13} pivoted on the front of the main plate b, and controlled by the spring b^{14}

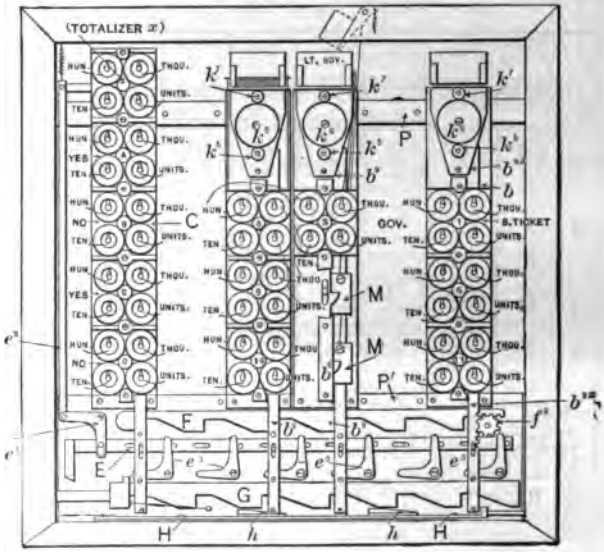

FIG. 474.

(Figs. 471 and 478). This pawl-and-ratchet mechanism permits only the forward or clockwise rotation of the key-piece b^{20}; and a voter having once chosen to actuate the card-delivering mechanism, he is prevented from voting upon the registers in that section. He must abide by his choice; the electoral franchise is not an unrestrained license. The law provides a remedy for inadvertence, but not for indecision on the part of the voter. And the votometer is constructed to conform to the law.

Where the local law permits, it is desirable to provide means for voting a "straight ticket." The "straight ticket" section is identical with the standard section first described, except that its vertical slide b^{35} (Figs. 470 and 477) is formed just below the main

plate b with a rack b^{23} that meshes with the pinion f^2. The registers of this section are assigned each to a party, and the actuation of a register counts one vote for each of the candidates of the party to which the register actuated is assigned. But the voter who has voted a "straight ticket" must be prevented from voting in the sections assigned to individual candidates. The following construction serves to limit such a voter to a legal ballot. The pinion f^2 (Figs. 470 and 477) that meshes with the rack b^{23} on the vertical slide b^{9x} meshes also with the rack f^1 on the interlock-

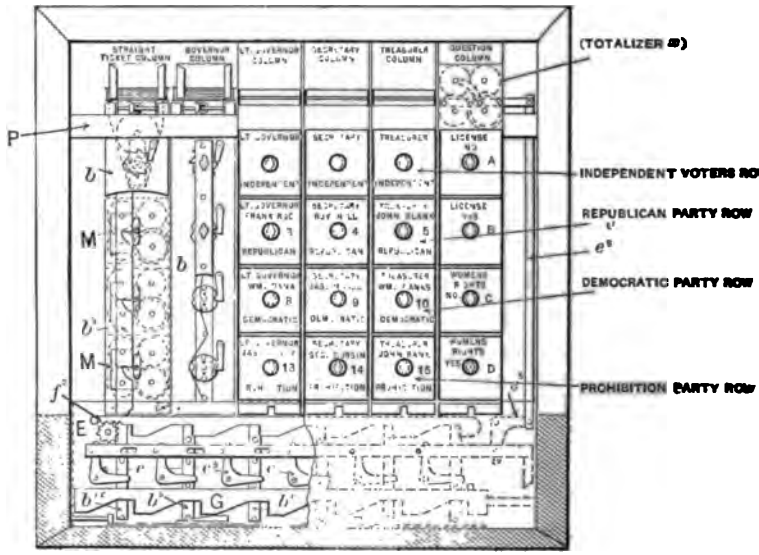

FIG. 475.

ing slide F. Vertical movement of the slide b^{9x} causes horizontal movement of the interlocking slide F, which is supported on studs f. When the vertical slide b^{9x} is raised by the actuation of a register in the "straight ticket" section, the interlocking slide F is moved so as to interpose its downwardly projecting portions over the studs b^{21} on the vertical slides b^9 of the sections assigned to individual candidates, thereby locking the said slides and all the register-actuators (or key-pieces) controlled by them. It follows, therefore, that the actuation of a register in the "straight ticket" section prevents the actuation of all registers assigned to individuals unless the voter counts off his vote, thereby lowering the slide b^{9x}, and restoring the interlocking

slide to its initial position. While in this initial position, the notches of the interlocking slide F are over the studs b^{20} of the vertical slides b^9 and so permit the free vertical movement of the slides. If one of the slides b^9 is raised, that is, if the elector casts a vote in one of the sections assigned to individual candidates, the slide b^{9x} cannot be raised and, therefore, a vote in the "straight ticket" section cannot be cast in addition to one for an individual. This limitation results from the interposition

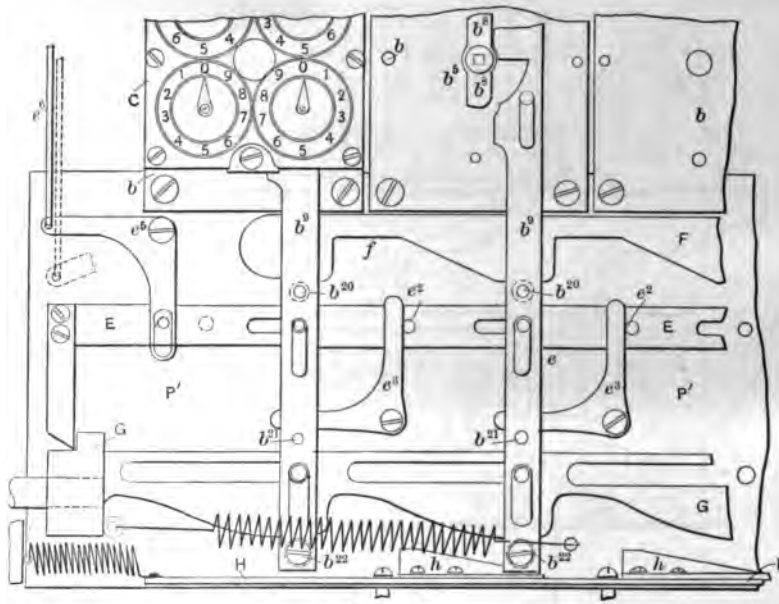

FIG. 476.

of the stud b^{20} of the vertical slide b^9 in the path of the interlocking slide F, as shown in Figs. 470 and 477. By removing the pinion f^2 the "straight ticket" feature is eliminated, and the section may be used as a standard section.

"*Question*" *Section*.—In the section reserved for questions the vertical slide is divided into as many parts V (Fig. 481) as there are questions submitted. These parts, V, are controlled by a supplementary resetting slide v^2. A single section has capacity for four questions. If "yes" is voted, the movement of the part V makes it impossible to vote "no" on the same question in addition, and *vice versa*, but any mistake may be corrected, as in other cases. It is to be noted that the inter-

locking slide *F* in no way controls this section, and voting a "straight ticket" may be done independently of an expression of opinion in the "question" section, and *vice versa.*

Selective or Group Sections.—For some offices it may be permissible to vote several times; as, for the office of school committee man the elector may vote as many times as there are vacancies in the committee. But he cannot vote more than once for the same candidate for the same office, even though

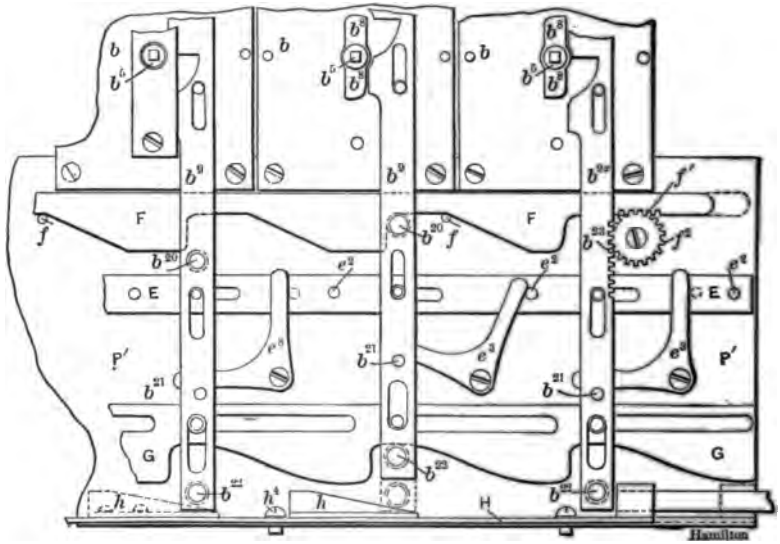

FIG. 477.

that candidate be nominated ("endorsed") therefor by more than one party. In the sections devoted to this selective or multiple voting the vertical slide is divided into as many parts as there are key-pieces in the column, and each of these parts is connected by means of a suitable rod with a limiting device which is attached to the base plate. This limiting device is adjustable, and may be set to permit the turning of the key a predetermined number of times; that is, a given number of candidates for a certain office may be voted for, and no more. Where a candidate is endorsed (*i.e.*, nominated by more than one party), the operation of one of the registers assigned to him prevents the operation of the others; therefore, an endorsed candidate can be voted for only once by the same voter, irrespective of the number of parties of which he is the nominee.

The Totalizer.—Mounted on the base-plate P^1 (Figs. 470, 476, 477) is the registering slide E provided with studs e. One arm of the bell crank e^3 normally rests against the stud e and the other arm against the stud b^{21} on the vertical slides b^9 b^{9x}. Vertical movement of the slides b^9 b^{9x} causes horizontal movement of the registering slide E, which is connected through the bell-

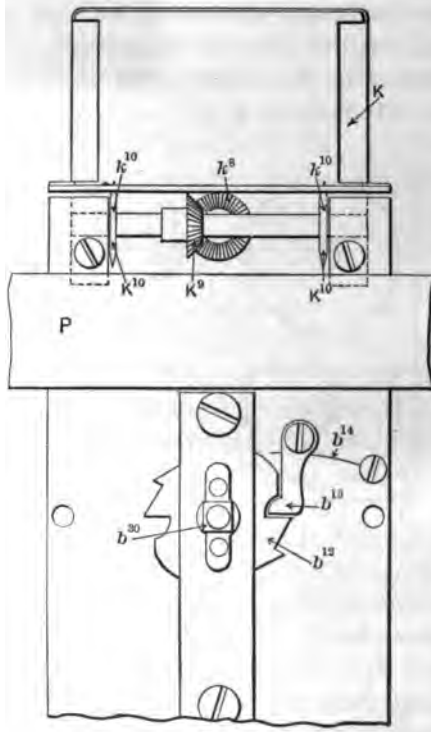

FIG. 478.

crank e^5 and rod e^6 (Fig. 476) with the counter or totalizer x (Figs. 474 and 475). The first turning of the key by the voter raises the vertical slide, moves the registering slide e horizontally, and actuates the totalizer x. Thus the totalizer registers the total number of voters who use the votometer, and no more.

The Cut-out Slide.—Where the suffrage is unequal (as in case of women voters, poll-tax payers), it is necessary to provide means by which to prevent the restricted voter from exercising the greater privilege of the regular voter. In the votometer the restricted voter is prevented from turning the key where he

is not entitled to do so by the following means: A "cut-out" slide *H* is attached to the lower part of the frame and adjacent to the base plate P^1 (Figs. 470, 476, and 477). To this slide *H* are detachably secured wedge-shaped pieces *h* adapted to engage the studs b^{22} on the lower ends of the slides b^9 b^{9x}. These pieces *h* are placed adjacent to the vertical slides of the sections that are denied to the restricted voter; and when such a voter presents himself, the inspector draws the cut-out slide *H* and thereby raises the vertical slides of the prohibited sections to their locking position by the engagement of the studs b^{22} with the inclined faces of the pieces *h*.

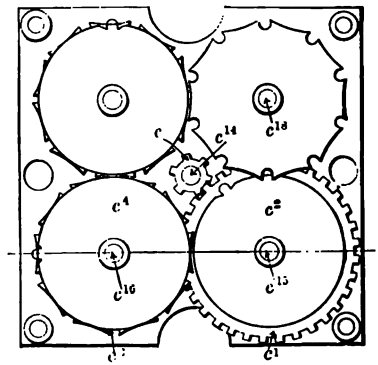

FIG. 479.

The Resetting Slide.—After the elector has voted, the votometer must be reset for the next elector. A resetting slide *G* (Figs. 470, 476, and 477) is secured to the base-plate P^1 and is formed with inclined faces that are adapted to engage the studs b^{22} on the lower ends of the vertical slides b^9 b^{9x} when said slides are raised. Fig. 476 shows the resetting slide *G* at the limit of its resetting movement, which is accomplished by the raising of the exit bar.

Entrance and Exit Bars.—The entrance and exit bars are connected with each other through the medium of the resetting slide *G*. Each is provided with a lock or bolt, but only one can be in a locked position at a given time. The entrance bar is unlocked and the registering mechanism locked by the act of raising the exit bar; and the exit bar and the registering mechanism are unlocked by the act of raising the entrance bar. When the entrance bar drops, it automatically locks itself, thus

preventing the exit of the voter by, or the entrance of others at, that end of the machine; and similarly the fall of the exit bar automatically locks the exit. Hence a voter cannot return after having once had an opportunity to cast his vote.

The Card Delivery.—An elector is privileged to vote for persons not on the official ballot, that is, to vote "independent." The independent voter is provided for by the card-delivering mechanism by means of which he is enabled to procure a card from a card box K at the top of each section (Figs. 470–472 and 478). The cards k are suitably printed under state control. The actuation of the key-piece b^{30} sets in motion the train of gears k^5, k^6, k^7, k^8, and k^9, and thereby rotates the star-wheel k^{10}, the teeth of which are in contact with the lowermost card. The card is thus fed through a slit sufficiently far to enable the voter to seize it. Only one card can pass through the slit at a time. The turning of the key-piece b^{30} raises the vertical slide b^9, thereby preventing the elector from turning any other key-piece in the section. The pawl-and-ratchet mechanism shown in Fig. 473 prevents the backward rotation of the key-piece b^{30}, as above explained. Hence the drawing of a card is final in that section and admits of no change of purpose. After the "independent" voter has indicated his choice on the card, he deposits it in a suitable receptacle provided therefor.

The Registers.—The inner end of the shank of the key-piece is provided with a pinion c (Fig. 479) that meshes with the gear c^1, fast on the shaft c^{15} of which is a single-toothed wheel c^2 and the pointer of the units-register. The shaft c^{16} carries the pointer of the tens-register, the shaft c^{17} that of the hundreds-register, and the shaft c^{18} that of the thousands-register. The operation of the register will be evident from a study of Fig. 479. The registers embody the interlocking feature of the Geneva movement, and another safeguard to accuracy and honesty of count is thereby added.

An important feature of the registering mechanism is that the voter, by means of his key, puts himself in direct positive mechanical connection with the register wheels. Only one operation is necessary, and thus is avoided the danger of mechanism failing to coöperate—a danger present where there are more operations than one. In the votometer the turning of the key is certain to operate the register. Again, the registers are operated one by one. Where, as in some voting machines,

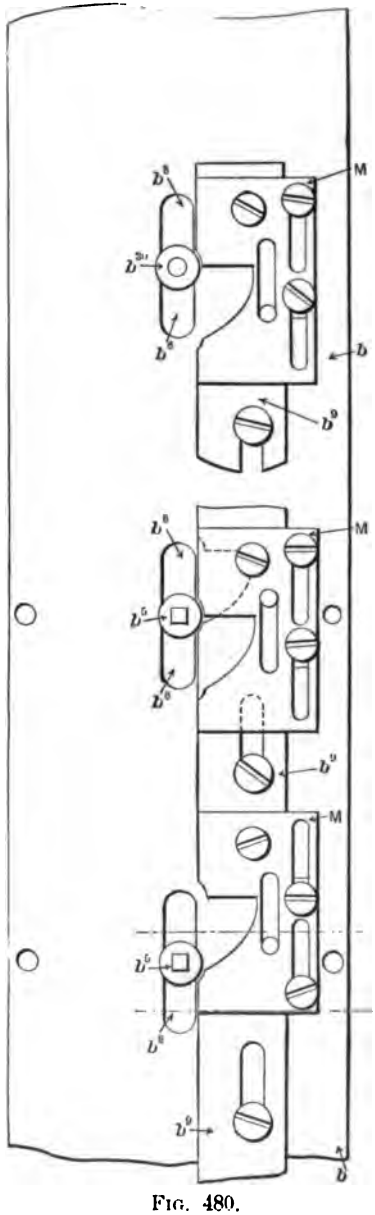

FIG. 480.

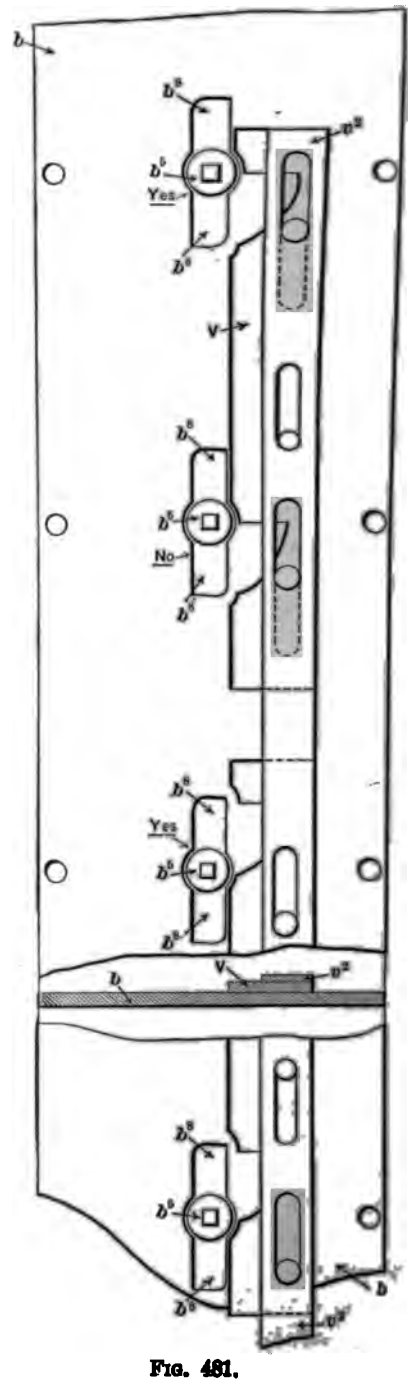

FIG. 481.

the voter first operates mechanism which selects the registers that he desires to actuate, and then operates a second mechanism that actuates all the selected registers, a defect in either mechanism may cause a failure to register the whole vote. And a lack of adjustment and coöperation between the selecting and the actuating mechanisms results in a failure to count on the register where the defect exists. Another safeguard is provided in the votometer system by the key, which is double-bitted. The bitts of the key prevent its withdrawal before the completion of the half-turn, and thus insure the completion of the necessary movement by the voter. As shown in Figs. 473 and 475, the keyhole is in the centre of the space allotted to the candidate. This arrangement guards against doubt on the part of the voter as to which register is assigned to a candidate. Another safeguard which insures that the voter shall not vote for one candidate under the impression that he is voting for another is found in the indicators *i*, which appear in the form of a cross-mark × to the right of the keyhole when the register is actuated. After having voted, the elector may step back from the machine and verify his vote by means of the indicators. Moreover, the appearance of the indicator assures the elector that the register has operated and his vote has been counted.

The ballot is protected by transparent material held in place by the frame *N*, rod *R*, and screw-eyes *r* (Fig. 473).

The registers are correspondingly numbered on front and back. This forms a ready means of identifying the registers with the candidates to which they are assigned. Where photographs of the front of the machine and the dials are taken for record purposes, as is usual, this numbering is found very useful in reading the record.

Operation.

A voter is given the key by the inspector and enters the machine by raising the entrance bar, which unlocks the exit and draws the main resetting slide *G* into a position which makes it possible to turn the key in any section of the machine. When it drops, the entrance bar automatically locks, thereby preventing the exit of the voter by, or entrance of others at, that end of the machine.

The voter finds upon the face of the machine the names of

the various parties and candidates arranged, either alphabetically or in party order, together with the questions, etc., that comprise the ballot (Figs. 468 and 475). The top horizontal row is devoted to the "independent" feature (or card delivery), by which a voter may vote for an individual whose name does not appear upon the ballot. In the type votometer there are 8 horizontal rows and 22 sections, of which 18 sections are assigned to the names of the candidates for the various offices, the names of candidates for the same office being arranged one above the other in the same section. The first and last sections are devoted to the emblems of the parties. The second section from the left is the "straight ticket" section containing the names of the parties, while the names of the candidates for the various offices are arranged in adjacent sections in regular order. The second section from the right is the "question" section.

Straight Ticket Voting.—The voter may make any legal selection he wishes. If he desires to cast by a single half-turn of the key a vote for all the nominees of a party, he confines himself to the "straight ticket" section, and, inserting the key in the proper hole—which is in the centre of the label (Figs. 473 and 475) bearing the name of the party for all the candidates of which he wishes to vote—he gives it a half-turn to the right, the limit of its motion. The effect of this half-turn is positively to actuate the register at the back. He cannot withdraw the key until he has completed a half-turn, and therefore registered his vote beyond peradventure. Simultaneously with the turning of the key, an indicator cross, or ×, appears at the right of the keyhole, showing at a glance where he has voted. It is now impossible to turn the key in any other hole in that section—that is, to vote an additional "straight ticket"; and it is also impossible to vote on a register assigned to an individual on the chosen ticket or any other ticket. However, the "question" section remains unlocked.

Voting on Questions.—The affirmative and the negative are each assigned a keyhole (Figs. 475 and 481), and the voter expresses his opinion on the question by inserting and turning the key in one keyhole or the other, according to his view. The indicator-cross appears, as before, to apprise the voter that that register has counted. Additional questions that may be upon the ballot may be voted upon in the same manner. If "yes" is voted on any given question, it is impossible to vote

"no" thereon in addition, and *vice versa*. After having voted a "straight ticket," and on the questions, it is impossible to turn any key forward, or clockwise.

Correcting Mistakes.—All that can now be done is to correct mistakes. Any register that the voter has moved forward he may move backward to the same degree—that is, to count off his own vote, but no other. The indicators show the voter which registers have been moved by him. If he discovers that the cross shows at the right of the keyhole assigned to a party for which he did not intend to vote—in other words, if he finds he has made a mistake by turning the key in the wrong hole—he may re-insert the key and turn it backward (counter-clockwise), thus counting off that vote. He may now make a new choice, with the same limitation as before. The same course may, if desired, be followed in regard to the vote on the questions. Thus all mistakes made by the voter may be corrected without loss of privilege.

Resetting and Locking on Exit.—The voter leaves the machine at the opposite end to that at which he entered and returns the key to the Inspector. In passing out he raises the exit bar, which is similar to the entrance bar, and thereby simultaneously resets and locks the registering mechanism, in which condition it remains until the next voter raises the entrance bar; so that should he, or any other, surreptitiously return, it would be impossible to cast a vote or to turn off any already cast. The exit bar drops to its horizontal position, in which it locks itself and remains locked until the next voter enters. Every voter finds it impossible to gain access to the face of the machine before his predecessor has passed out; that is, the bar at the entrance end of the machine cannot be raised until the bar at the exit end has been operated.

Irregular Voting.—Another voter enters as did the first, and, desiring to vote "irregular" or a "split" ticket, he neglects the "straight ticket" section, and votes for his candidates individually—selections from different parties. The construction of the votometer is well adapted to the expeditious and easy voting of a "split" ticket. The registers are operated one by one; and the turning of the key-piece of a register completes in one simple and familiar operation the vote for the candidate to which the register is assigned. The voter cannot go wrong, for the mechanism limits him to a legal ballot, the keyhole is

in the centre of the label. and the indicators show him for whom he has voted.

Independent Voting.—Instead of actuating a register assigned to a party or to an individual, the independent voter actuates a card-delivering mechanism by turning the key in the top-row and in the key-hole assigned to the office for which he desires to name a candidate. From a slit immediately above the key-hole there appears simultaneously with the turning of the key a card suitably printed, upon which he puts the name of the candidate for whom he wishes to vote. He may then deposit this card in the properly designated receptacle provided. By procuring a card the voter locks the registers of that section, and thereby denies himself the privilege of voting for any candidate for the office to which that section is assigned. But in the sections other than the "Straight Ticket" section, and those in which he has drawn a card, the voter may still actuate the registers and afterwards correct any mistake he may have made in doing so.

Selective Voting.—Where there are more vacancies than one in a given office (*e.g.*, coroner, judge, alderman-at-large), the machine may be suitably arranged, either to permit voting for all of the candidates of any one party for that office as a group at a single half-turn of the key, or so that each candidate may be voted for individually. In the first instance all of the nominees of the same party for the office in question are printed upon a single label and, consequently, are assigned a keyhole in common; it follows that a turn of the key counts a vote for each one of the group. In case the voter does not desire to vote for all the candidates in one group, or if he desires to vote for names found in different groups, he may vote "independent," draw a card and upon it make any proper combination of names he wishes, and then deposit the card as an independent vote.

In the second instance only one candidate's name appears upon the label, and the key may be turned in as many places for that office as the voter is entitled to vote for candidates therefor, and no more; that is, the predetermined number of candidates may be voted for, and they may be nominees of one party or of different parties. In any case it is impossible to vote more than the legal number of times.

The Endorsed Candidate.—When the voter is entitled to vote for more than one candidate for a certain office and one (or more) of the candidates has been "endorsed" (that is, has been

nominated by more than one party for that office), the limiting mechanism provided makes it impossible for the elector to vote for such a candidate more than once for that office, although his name appears more than once for that office on the ballot. Such a candidate may be voted for as the nominee of the chosen party, and the vote counts for him only as the nominee of that party.

Class Voting.—Certain voters (*e.g.*, women voters, poll-tax payers) are restricted in their right of suffrage to certain offices (*e.g.*, school committee). When such a voter appears, a key which is accessible only from the back of the machine is turned by the Inspector, until the attached indicator shows the voter and any other present that the machine is properly set so as to prevent her from exceeding her privileges. Upon entering the machine she finds it impossible to turn the key except in the sections where she is legally entitled to do so. After the exit of a restricted voter, the machine is properly adjusted by the Inspector, by means of the key on the back of the machine, for the next regular voter.

Any keyholes which are not in use may be covered with suitable metal caps that are provided with the machine, thus preventing the turning of the key where the labels are blank.

If during the poll it is desired to replenish the supply of cards in the upper part of the votometer, the upper part of the hinged cover is unlocked and access is thereby gained to the card boxes without exposing the registers. At the closing of the polls the entire cover is removed, thereby exposing the register dials, which are then read and photographed.

Summary.

1. The votometer secures absolute secrecy. The only trace left by the voter of his manipulations is the change of position of the register pointers, and this change is hidden by the votometer casing.

2. No defective vote can be cast. There are no technical requirements to be complied with or violated by the voter. The vote of every elector is equal in its influence upon the result to the vote of every other elector. The choice of every voter finds expression upon the votometer and has its influence on the result.

3. No vote can be invalidated by the dishonesty or carelessness of the election officer.

4. No illegal ballot can be cast. Every ballot cast upon the votometer is legal and effective.

5. While the votometer effectually prevents the casting of an illegal or defective ballot, yet it gives the voter every opportunity to correct his mistakes. Indicators show him which registers have been actuated by him and the mechanism permits him to cancel his own vote but stops him from cancelling any vote not cast by him.

6. The operation of the mechanism is sure. The parts are in positive mechanical connection with each other so that the turning of the key by the voter is absolutely certain to register his vote. To vote requires only one operation, simple and familiar. There is no chance of failure due to lack of coöperation of successive movements of the mechanism. No fine adjustments are necessary. The voter cannot withdraw the key until he has completed the half-turn necessary to register his vote.

7. The sectional construction of the votometer gives an elasticity of arrangement which permits the votometer to be adapted to the requirements of any election and of the laws of any state.

8. The "independent" voter, the "irregular" or "split ticket" voter, the "party" or "straight ticket" voter, and the woman voter are specially provided for and are permitted to exercise freely the privileges given them by law, while restricted to those privileges.

9. The mechanical registration of the votes insures accuracy, avoids the necessity of recounts, and relieves election officers and the courts of the necessity of passing upon close and perplexing questions of the legality of ballot markings.

10. The votometer reduces the expense attending elections, promotes convenience and rapidity of voting, and gives no opportunity for dishonest practices on the part of voters or election officers.

APPENDIX.

Opinions of the Justices of the Supreme Judicial Court.

The following communications were received from the Justices of the Supreme Judicial Court:

To the Honorable the House of Representatives of the Commonwealth of Massachusetts:

Opinions of the Justices of the Supreme Judicial Court —use of voting and counting machines at elections.

The undersigned Justices of the Supreme Judicial Court having considered the question proposed by the Honorable House of Representatives, by its order of March 29, 1901, a copy of which is annexed, respectfully submit the following opinion:

The ground for doubt as to the power of the General Court under the Constitution of the Commonwealth is to be found in the requirement that representatives "shall be chosen by written vote," Part 2, c. 1, § 3, art. 3, and in the implication of the provisions for sorting and counting the votes for governor, c. 2, § 1, art. 3, and for senator, c. 1, § 2, art. 2. To these may be added the requirement that certain militia officers shall be elected by written vote, c. 2, § 1, art. 10, and articles 16 and 17 of the Amendments, one or both of which might be held to adopt the method of voting for governor for the election of certain other officers. Whether the first mentioned requirement, as to representation, has been repealed by art. 21 of the Amendments, giving the Legislature power to prescribe the "manner of ascertaining" the election of representatives, it is unnecessary to consider, although it may be well to bear that Amendment in mind in weighing the arguments which we shall adduce. Apart from these provisions, no doubt, the general power of the Legislature would extend to authorizing the use of a voting machine. See for example Amendments, art. 19.

With regard to votes for Representatives in Congress it is provided by c. 154 of the Statutes of the United States for 1899, that they may be by "voting machine the use of which has been duly authorized by the State law," so that the elections of national officers require no separate consideration.

We assume that the voting machines which the Honorable House has in mind vary in their mode of recording votes, that all of them dispense with the use of a separate piece of paper for each vote, that some of them register a large number of successive votes by successive punches upon one strip of paper, in separate lines for separate candidates, with the names, if necessary, against the lines, and that some of them abandon the use of paper altogether in recording, each vote being marked by the partial revolution of a cog-wheel or other similar device, and the total number being shown by some easily adapted index. If necessary, however, in this class of machines the names of the candidates may appear in writing attached to the point where the voter registers his vote, in such manner as to indicate that his turning a particular key or pressing a particular knob expresses a vote for the name written above.

The question whether such a machine satisfies whatever requirements or implications there may be in the Constitution of the Commonwealth, depends upon how far we are to follow the line of argument started by Chief Justice Parker in *Henshaw* v. *Foster*, 9 Pickering, 312. In that case it was pointed out, with regard to this very matter, that, as the Chief Justice puts it, "words competent to the then existing state of the community, and at the same time capable of being expanded to embrace more extensive relations, should not be restrained to their more obvious and immediate sense, if, consistently with the general object of the authors and the true principles of the compact, they can be extended to other relations and circumstances which an improved state of society may produce." (Page 317.)

To state in our own way the mode of approaching the question, it is not so important to consider what picture the framers of the Constitution had in their minds, as what benefits they sought to secure, or evils to prevent—what they were thinking against in their affirmative requirement of writing, and what they would have prohibited if they had put the clause in a negative form. The answer, or a part of it, is given by Chief Justice Parker in the case already cited: "The practice had been to elect many town officers by hand vote, and probably in some instances representatives had been so chosen. It became necessary, therefore, to prescribe that the choice should be made by ballot: but even the word *ballot* itself is ambiguous, and therefore it was required that representatives shall be elected by writ-

ten votes." No doubt the picture in the minds of those who used the words was that of a piece of paper with the names of the candidates voted for written upon it in manuscript, but the thing which they meant to stop was oral or hand voting, and the benefits which they meant to secure were the greater certainty and permanence of a material record of each voter's act and the relative privacy incident to doing that act in silence. They did not require the signature of the voter, or any means of identifying his vote as his after it had been cast. It was settled by *Henshaw* v. *Foster* that they did not require manuscript. In our opinion they did not require a separate piece of paper for each voter. That is to say, by requiring writing they did not prevent the Legislature from authorizing several voters to use a single ballot if the voters all signed it, or in some way sufficiently indicated that a single paper expressed the act and choice of each. It seems to us that the object and even the words of the Constitution in requiring "written votes" are satisfied when the voter makes a change in a material object, for instance, by causing a wheel to revolve a fixed distance, if the material object changed is so connected with or related to a written or printed name purporting to be the name of a candidate for office, that, by the understanding of all, the making of the change expresses a vote for the candidate whose name is thus connected with the device.

So far we have been considering the requirement of written votes alone, and have assumed that all other constitutional conditions are complied with. But it remains to consider whether the result is changed by the provisions as to sorting and counting votes where those provisions apply. These seem to us to raise less difficulty. The provisions do not express a constitutional end; they express merely assumptions that sorting and counting will be necessary if you have written votes, as they would have been necessary a hundred years ago. It would not be true to say that the framers of the Constitution chose the risk of errors incident to sorting and counting in preference to the risk of errors of a different class incident to some different way of finding out the result. They never thought of any other way. Probably the only distinctions which occurred to them concerned different modes of sorting and counting.

It is theoretically possible to exclude by a mechanical device every chance of error in the sorting and counting of votes.

Whether that is accomplished by existing machines is a matter about which we have no adequate information, and is a question of fact which it would not fall within our province to determine. We assume that the Legislature before authorizing the use of a machine would satisfy itself that the voter would be sufficiently apprised of what to do in order to vote for his candidate, that the machine really would carry out and express the intent which it purported to be ready to express, that it was of such mechanical perfection as to exclude the possibility of internal error, and that sufficient arrangements were made to prevent external fraud. Under such circumstances the sorting and counting of the votes shrink by atrophy to a mere survival, but there is nothing contrary to the Constitution in that. If it be deemed technically necessary that the possibility at least of sorting and counting should remain, it does remain. Whether in the form of successive punches in a line upon paper, or in the marked revolutions of a wheel appropriated to a given candidate, material changes abide which signify by predetermined language the number of votes cast, exactly to the same extent that it would be signified by slips of paper bearing characters in printer's ink. The votes could be counted as cast, if it were necessary. They can be counted afterwards as well. The fact that the index of machinery has cut down the chance of personal error to a minimum surely is not an objection sanctioned by the Constitution.

The views which we express coincide with the opinion of a majority of the Judges of the Supreme Court of Rhode Island in regard to the McTammany machine (19 R. I. 729), and with some other discussion of the subject which we have seen.

It is proper to add that we have considered only the answer to the general question. What provisions should be made in the exceptional case of challenged votes, etc., is a question of detail, easily dealt with by special arrangements.

OLIVER WENDELL HOLMES.
MARCUS P. KNOWLTON.
JOHN LATHROP.

I agree with this conclusion, provided the result of the action of the machine in registering each vote cast is visible to the voter casting the vote, and the work of the machine, in adding up the votes cast, is done under the supervision of some person duly charged with counting the votes cast.

I agree that machinery can be used by the voter in making a written vote within the meaning of the Constitution, and also that there is nothing in the Constitution which forbids machinery being used in counting the votes cast.

The first difficulty, in holding that the provisions of the Constitution are complied with by any one of the several voting machines which are now in use (so far as I know), comes from the fact that in none of them can the voter see what his written vote is. In the method of voting prescribed by the Constitution, the voter knows what the written vote cast by him is. It is manifest that the use of a voting machine, which records a written vote without disclosing to the voter what that vote is, involves chances of error quite different from those involved in the method of voting contemplated by the Constitution. There are similar difficulties arising from the fact that the addition of the several votes cast made by many of the voting machines is also invisible, and that the correctness of the result produced by the machine depends entirely upon the machine's having made the addition correctly in the first instance, without the possibility of knowing whether that addition was or was not correctly made, and without the possibility of correcting it, if it was not correctly made. And again, the only guard against a voter's casting more than one vote lies in the fact that the mechanical device put into the machine to prevent double voting has worked correctly, and in that fact alone, without there being any means of knowing whether it did or did not work correctly, and without the possibility of correcting such a fraud if one were committed.

It is manifest that in the matter of the record made by the machine being in each instance what the voter intended his vote should be, in the matter of the several votes cast being correctly added together by the machine, and in the matter of double voting, the chances of error involved, where the result of an election is made to depend solely upon the result produced by the voting machine, are quite different from those incident to the method of voting contemplated by the Constitution, at least so far as the voting machines now in use are concerned. And, in my opinion, the chances of error to which I have referred are so far different as to forbid votes cast and counted only by such a machine being held to be a compliance with the provisions of the Constitution in that connection.

It is evident that the use of voting machines which I have

suggested would destroy to a great extent the secrecy of the ballot; but I find nothing in the Constitution requiring that the written vote there provided for should be a secret one.

It has been suggested that a machine could be devised, which would indicate that a vote had been cast for some person for a designated office, without disclosing the person voted for; and that by the use of such a machine the secrecy of the ballot could be maintained and the requirements of the Constitution met. In my opinion, the use of such a machine would not meet the requirements of the Constitution.

WILLIAM CALEB LORING.

To the Honorable the House of Representatives of the Commonwealth of Massachusetts:

The undersigned Justices of the Supreme Judicial Court respectfully submit the following, as their opinion upon the question of law stated in your order of March 29, 1901, which question is:

"Has the General Court the right to authorize the use of voting and counting machines at elections by the people of national, state, district, county, city, or town officers?"

First. As to county, city, and town officers, and as to officers chosen by districts, other than councillors, senators, and representatives, we know of no constitutional restriction upon the power of the General Court to direct the manner of choice.

Second. As to councillors, senators, and representatives, and as to the governor, lieutenant-governor, secretary, treasurer and receiver-general, auditor, and attorney-general, there are constitutional provisions which must be considered in answering your question.

The provisions to which we refer are these:

Declaration of Rights, art. 9. "All elections ought to be free. . . ."

Part Second, c. 1, § 1, art. 4. "And further full power and authority are hereby given and granted to the said General Court from time to time to make, ordain, and establish all manner of wholesome and reasonable orders, laws, statutes, and ordinances, directions and instructions, either with penalties or without; so as the same be not repugnant or contrary to this Constitution, as they shall judge to be for the good and welfare

of this Commonwealth, and for the government and ordering thereof, and of the subjects of the same, and for the necessary support and defence of the government thereof; and to name and settle annually, or provide by fixed laws for the naming and settling, all civil officers within the said Commonwealth, the election and constitution of whom are not hereafter in this form of government otherwise provided for. . . ."

Part Second, c. 1, § 2, art. 2. "The Senate shall be the first branch of the Legislature; and the senators shall be chosen in the following manner, viz. . . . The selectmen of the several towns . . . shall receive the votes of all the inhabitants of such towns, . . . and shall sort and count them in open town meeting, and in presence of the town clerk, who shall make a fair record, in presence of the selectmen, and in open town meeting, of the name of every person voted for, and of the number of votes against his name; and a fair copy of this record shall be attested by the selectmen and the town clerk, and shall be sealed up, directed to the Secretary of the Commonwealth, for the time being, with a superscription expressing the purport of the contents thereof, and delivered by the town clerk of such towns, to the sheriff of the county in which such town lies. . . ."

Chapter 1, § 3, art. 3. "Every member of the House of Representatives shall be chosen by written votes."

Chapter 2, § 1, art. 3. "Those persons . . . qualified . . . within the several towns of this Commonwealth, shall, at a meeting to be called for that purpose . . . annually, give in their votes for a governor, to the selectmen, who shall preside at such meetings; and the town clerk, in the presence and with the assistance of the selectmen, shall, in open town meeting, sort and count the votes, and form a list of the persons voted for, with the number of votes for each person against his name; and shall make a fair record of the same in the town books, and a public declaration thereof in the said meeting; and shall, in the presence of the inhabitants, seal up copies of the said list, attested by him and the selectmen, and transmit the same to the sheriff of the county . . ."

Chapter 2, § 1, art. 10. "The captains and subalterns of the militia shall be elected by the written votes of the train-band and alarm list of their respective companies; the field officers of regiments shall be elected by the written votes of the captains and subalterns of their respective regiments; the brigadiers shall

be elected in like manner, by the field officers of their respective brigades. . . ."

Chapter 2, § 2, art. 1. "There shall be annually elected a lieutenant-governor . . . in the same manner with the governor . . ."

Amendments. Art. 16. "Eight councillors shall be annually chosen by the inhabitants of this Commonwealth, qualified to vote for governor. The election of councillors shall be determined by the same rule that is required in the election of governor. . . . The day and manner of the election, the return of the votes and the declaration of the said elections, shall be the same as are required in the election of governor. . . ."

Art. 17. "The secretary, treasurer, and receiver-general, auditor, and attorney-general, shall be chosen annually. . . . The qualification of the voters, the manner of the election, the return of the votes, and the declaration of the election, shall be such as are required in the election of governor. . . ."

Art. 21. ". . . The manner of calling and conducting the meetings for the choice of representatives, and of ascertaining their election, shall be prescribed by law. . . ."

Art. 22. ". . . Each district shall elect one senator. . . ."

Art. 24. "Any vacancy in the Senate shall be filled by election by the people of the unrepresented district, upon the order of a majority of the senators elected."

In our opinion the requirements as to the choice of senators found in Part Second, c. 1, § 2, art. 3, of the Constitution were not abrogated by articles 22 and 24 of the Amendments, nor was the provision of Part Second, c. 1, § 3, art. 3, that "Every member of the House of Representatives shall be chosen by written votes," abrogated by article 21 of the Amendments.

The provision that representatives shall be chosen by written votes was before this court in the year 1830 in the case of *Henshaw* v. *Foster*, 9 Pickering, 312, in which decision it was held that printed votes are written votes within the meaning of the provision.

The same decision states the general considerations which should have weight in construing the provision, and with that statement we agree: "In construing so important an instrument as a Constitution, especially those parts which affect the vital principle of a republican government, the elective franchise, or the manner of exercising it, we are not, on the one hand,

to indulge ingenious speculations, which may lead us wide from the true sense and spirit of the instrument; nor, on the other, to apply to it such narrow and constrained views as may exclude the real object and intent of those who framed it. We are to suppose that the authors of such an instrument had a thorough knowledge of the force and extent of the words they employ, that they had a beneficial end and purpose in view, and that more especially in any apparent restriction upon the mode of exercising the right of suffrage, there was some existing or anticipated evil which it was their purpose to avoid.

"If an enlarged sense of any particular form of expression should be necessary to accomplish so great an object as the convenient exercise of the fundamental privilege or right, that of election, such sense must be attributed. We are to suppose that those who were delegated to the great business of distributing the powers which emanated from the sovereignty of the people, and to the establishment of rules for the perpetual security of the rights of person and property, had the wisdom to adapt their language to future as well as existing emergencies; so that words competent to the then existing state of the community, and at the same time capable of being expanded to embrace more extensive relations, should not be restrained to their more obvious and immediate sense, if, consistently with the general object of the authors and the true principle of the compact, they can be extended to other relations and circumstances which an improved state of society may produce."

The decision from which we have quoted applied these principles; and because printing was, in law, writing from a time before that when the Constitution was made, and because the use of printed votes was equally well calculated to avoid the evils which the framers of that instrument thought would attend elections if conducted by nomination and hand vote, or *viva voce*, the court held that printed votes were constitutional, although the uniform practice had been, for some fifty years, to use manuscript votes only.

The same decision says further: "This requisition of written votes in the Constitution is confined to the choice of representatives. The important election of governor, senators, and councillors, is left unprovided for in this respect, except by implication, and that implication does not exclude printed votes. The votes of all the different communities were to be sorted and

counted, and a certificate of the result transmitted to a common focus, the secretary's office, where they were to be examined and compared. This process *necessarily* requires tickets or ballots, so that there was no occasion to require expressly that the votes should be in writing or in print. There can be no ground to exclude printed votes for these State officers, for all that is required is that they should be so given as that they may be sorted and counted."

Bearing in mind the statement of the Declaration of Rights that "All elections ought to be free," and also the general rules laid down in the case of *Henshaw* v. *Foster*, we have examined the published laws under which, during our colonial and provincial periods and the interval between the Declaration of Independence and the inauguration of our present government, officers have been chosen or appointed. Without giving the citations, it is enough to say that such an examination shows that while higher officers often were chosen by the casting of separate paper votes by the individual voters, some elections were made by the use of Indian corn and beans, as ballots, and that as to much the greater number of officers chosen by the people there was no specific direction as to the manner in which the choice of the individual voter should be expressed; but representatives to the General Court were selected by the voters in town, district, or plantation meetings, the votes being given under statutory directions as to the manner of voting contained in Prov. St. 1693–4, c. 14, §§ 2, 6, 7; 1 Prov. Laws (State ed.), 147. These directions provide that no voter shall put in more than one vote for any one person, and that "All persons shall put in their votes unfolded to the selectmen or constables appointed to receive the same." These provisions plainly imply that the only legal method of voting for representatives under the provincial government was for each voter to put in his own separate written vote. An examination of the printed records of the town of Boston shows that this was the method there used up to 1780, and the only reason we have found for supposing that representatives to the General Court of the Province ever were chosen by nomination and hand-vote, or *viva voce*, is the statement in the decision in *Henshaw* v. *Foster*, at page 319, that "probably in some instances representatives had been so chosen."

In most elections the votes given in at town meeting were not

preserved after the declaration of the result in open meeting. But in the case of the nomination of magistrates or assistants under the Massachusetts Bay Colony charter, the votes cast in the meetings were there sealed up and then carried to the shire towns, and from each shire town to Boston, where they were finally opened, and the result of the voting in the towns and plantations ascertained. And in the case of county treasurer and registers of deeds under the provincial government, the votes given in by the individual voters at the town meetings were there sealed up, and taken to the Court of Sessions of the county, and opened and sorted in the presence of the justices by men appointed by them for the purpose, and the result thus ascertained in that court.

Interpreting the Constitution in the light of the circumstances existing at the time of its adoption as well as of the laws and customs which had theretofore prevailed, we think that the language prescribing the way in which the will of the voters shall be expressed and ascertained in the case of the election of governor and of the other State officers, where similar language is used, necessarily implies at least that the choice of the voter shall be indicated by some kind of writing upon a paper or other material thing; that this material thing, bearing this written expression of the choice of the voter, shall by his act of voting pass from his possession and control into that of the officers charged with the duty of conducting the election, and that the voter shall have reasonable opportunity to see that it has so passed, that it shall be distinct from that handed in by any other voter, and that these written votes so handed in shall continue to be the same material things capable of being handled, sorted, and counted, and that the whole work of ascertaining and declaring the result shall be the personal act of the election officers, with the written votes before them, the sorting and counting as well as the declaration of the result being done by sworn officers. One reason for the requirement of a written vote is that the voter may have a reasonable opportunity of making his choice without immediate influence upon the part of others; and the reason for the requirements applicable to the sorting and counting is that the votes may not fail of their proper force by reason of mistake or fraud in the count. The safeguard erected by the Constitution is that there shall remain after the closing of the voting, in a material form, capable of being read and understood

by men, a written vote cast by each voter; and that all these individual votes, each given by the voter to the election officers, shall be read, sorted, and counted in accordance with the several tenor of each, by men acting under the sanction and obligation of their respective official oaths.

So far as we have been informed as to the nature of the machines mentioned in your order, none of them provides for or allows the individual voter to have in his own hands a paper or other material thing bearing upon itself the expression of his choice; none of them allows him to cast or deposit in the custody of the election officers a paper or other material thing bearing such expression as his individual written vote; and none of them, upon the casting of the vote, or at the closing of the polls, places in the hands of the election officers a separate, material thing given in by the voter, which the officers can handle, sort, and count. None of them is so built and worked that the voter can know that, unless sworn officers err or are false to their oaths, the choice which the Constitution commands him to express by "written vote" will be counted, and counted as he cast it. Yet to give him that certainty, and to give the State the safeguard which comes from his having that certainty, is one purpose of the constitutional requirement of "written votes," "sorted and counted" in open meetings, so that each vote must have its legitimate weight in the election, unless an intelligent and responsible man fails in the performance of a simple, sworn duty.

The turn of a wheel or of a dial, the punching of a hole in an unseen roll of paper on which are the names of candidates, by a voter who pulls a lever or turns a key, is not the use of a written vote within the meaning of the Constitution; nor is the inspection of a dial, even if preceded or followed by an inspection of all the cogs and mechanism which have moved the hands of the dial, or the counting of holes in such a paper and the inspection of the machinery which made the holes, the sorting and counting of votes by election officers. If it be said that these are the best and most efficient means to secure a free and honest election, the answer is that they are not the means prescribed for those ends by the Constitution. The Constitution does not authorize the General Court to put the expression of the voter's will to the chance of being nullified or perverted by slipping cogs, defective levers, or other mechanical devices which have no living intelligence, no conscience, and no liability to punish-

ment to insure their going right. It requires that every step in the task of seeing that votes, whether given by Indian corn and beans or other ballots, by show of hands, by the living voice, or by paper writing, are counted rightly, shall be intrusted to and performed, not by an inanimate machine, but by sworn officers, and in open meeting, where each step of the work can be verified and mistakes corrected.

In our opinion the General Court has not the right to authorize the use of the machines mentioned in your order, at elections by the people of the governor, the lieutenant-governor, the councillors, senators and representatives, the secretary, the treasurer and receiver-general, the auditor, or the attorney-general.

A law of Congress requires votes for representatives in Congress to be by written or printed ballot, or voting machine the use of which has been duly authorized by State law. In our opinion the General Court has the right to authorize the use of machines referred to in your order, in elections for representatives in the Congress of the United States.

In the case of electors for President and Vice-President, it might, perhaps, be different, although long usage has given to the manner in which they are now chosen almost the force of an inviolable sanction.

JAMES M. NORTON.
JAMES M. BARKER.
JOHN W. HAMMOND.

DISCUSSION.

Prof. R. H. Thurston.—As a member of the New York State Commission on Voting Machines, which has examined and accepted that here described, I am much interested in securing the views of members of the Society regarding the wisdom of their use; and, as a member of the Society and of the profession, I am greatly concerned to secure the simplest and the most perfectly reliable possible system of record of votes by mechanical means. We are all concerned in the promotion of every effort to insure the prevention of fraud at the polls and the elimination of all immoral, illegal, and treasonable practices in the use of a political privilege which is the highest ever enjoyed by man. I think this class of inventions one of the most important of our time.

A considerable number of States already have laws permitting

the use of the ballot-machine, and it seems now possible that all will soon fall into line; for the success of the mechanical system of registration of votes has thus far been remarkably encouraging. In most of the States which have such permissive laws, the provisions are excellent. New York has a good law and one which permits the assurance of every inventor that his device shall be given careful study and admitted if found safe for use, and that no selfish interests shall either secure a monopoly or shall bar him out individually. Should a monopoly be secured, the next inventor bringing in a novel but efficient machine may break it. If the people of any city find themselves threatened with extortion by a monopoly, they can go back to their earlier system of voting. In a few States, possibly—certainly in Rhode Island for one, if we may accept the testimony of the press of that State—the law is the product of either ignorant or interested legislation, and is so worded that the best devices of the day are discriminated against and less satisfactory machines are favored. But this, if it be a fact, is an exception to the rule, and it probably cannot long so remain. Massachusetts has an excellent law, and several of the middle Western States have proceeded in this direction with admirable discretion.

Some of the machines earlier employed have been found by experience not to be satisfactory; but that is simply the usual history of new systems of construction in all branches of engineering and mechanics. There are now a number of machines which are working successfully and satisfactorily to the voters.

At a recent election in my own city, where about 3,000 votes are cast as a maximum, the figures were reported from the polls, at the City Hall, in *seventeen minutes* after the clock struck five, the hour for closing, and the boys on the street were selling their "extras" in fifteen minutes or a half hour at most. In Buffalo, where there are over 100 machines and a population of about 300,000, the record stands at about one hour after closing. Compare these figures with the day or more of delay in reporting the results which sometimes make a nation wildly impatient on the occasion of important general elections.

The machines which have come into use are, as is seen by the example before us, very simple elements aggregated in a very simple manner; so that, while the number of parts is great, there is very little liability to get out of order, and, in fact, experience shows that the losses of ballots and the disfranchise-

ment of voters by the machine when of an approved construction is enormously less than in the old system through the simple errors of voters failing to correctly mark their ballots; while the constant danger, under that older system, of a disputed count, the greatest danger of our elective system, is here entirely eliminated. The count is made automatically and by the machine, and cannot be challenged by either party to any political controversy.

A properly constructed machine permits the following essential objects to be accomplished by the voter:

(1) To vote in absolute secrecy.
(2) To vote rapidly, and in the most convenient way possible.
(3) To vote a straight party ticket, by operating one knob which moves all the indicators on that ticket.
(4) To vote for the entire ticket by moving an indicator over the name of each candidate separately.
(5) To vote as he may choose from candidates from any party, or for persons not named on any ticket.
(6) To vote for all the candidates for whom he is entitled to vote, at the same time preventing him from exceeding the privilege given him by law.
(7) To examine the ticket he has voted and make any changes he desires, until he is satisfied with his choice, before registering it and leaving the booth.

As chairman of the Finance Committee of the Municipal Council of the city of Ithaca, N. Y., a few years ago, I had occasion to study this, which has seemed to me an important advance in mechanics as well as in social and political life, and the conclusions reached and reported, in which our committee were unanimous, were the following:

(1) The voting machine is a simple, reliable, durable, and convenient apparatus for its purpose.
(2) The machine compels the deposit of a perfect and accurate ballot, of the form chosen by the voter.
(3) It restricts the voter absolutely to the limits of the law and permits him freedom as absolute in voting within that limit.
(4) Blank and defective ballots, the usual fault of ordinary methods of voting, are entirely done away with, and no man loses his vote through defect of the system, or fault of his own, if he votes at all. The disfranchised voter becomes unknown.
(5) Fraudulent voting is impossible, as well as errors in voting.
(6) The vote cast is registered, vote by vote, with absolute accuracy and certainty.
(7) The result can be declared immediately upon the close of the polls, having been already completely counted.
(8) The cost of the system is so much less than that of the old method, that the machines usually pay for themselves in from three to seven years.

[illegible] The machines [illegible] [illegible] methods of balloting." Their [illegible] they involved a more costly [illegible] [illegible] The adoption is looked upon by your [illegible] good [illegible] and good finance.

[illegible] some time since, when the whole country [illegible] the outrages perpetrated by traitorous [illegible] of States, a well-known journal remarked, [illegible]:

"[illegible] in Kentucky that forms the strongest argument [illegible]. These are in use in several cities in the State of New York [illegible] with the greatest success in Buffalo. Voting by [illegible] every State in the Union, and with particular [illegible] Kentucky."

About 25[illegible] of these machines are in use in the State of New York; but it is perhaps hardly necessary to say that New York is not one of the cities in which they have been adopted. Yet the largest number of them is to be found in Buffalo, the next largest city of the State, and where there has been, at times, serious infringement of public and private political rights. Of the first experiment the outcome, as reported at the time by a Buffalo paper, an extract from which I find in my scrap-book, was the following:

"In the elections on Tuesday 225 voting machines were used in this State, distributed as follows: Buffalo, 108; Rochester, 73; Utica, 26; Ithaca, 10; Albion, 5; Canisteo, 2; West Winfield, 1. Extra machines, held in reserve to meet accidents or other emergencies, are not included in the enumeration.

"High praises of the machines come from all quarters. They have met every promise of convenience to voters, speed in voting, automatic and instantaneous footing of the total number of votes cast for each candidate, and a promptness in announcing the aggregate result in a city or village proportioned to the quickness with which the returns from each district were conveyed to a central point and tabulated.

In addition to their speed and accuracy the machines are so constructed as to make it impossible to cast a defective vote, to 'repeat,' or to commit any fraud or irregularity. On the score of guaranteeing to every citizen the exercise of the voting privilege, without risk of disfranchisement on account of blunders, the machines seem absolutely perfect. Their superiority to the official ballot in this respect is plain and striking, and is demonstrated by official records.

"All in all, the voting machine is one of the inventive triumphs of the age, and it is as sure, in the near future, to displace the printed ballot as steam has proven to be in putting out of date the stage coach and the packet boat."

Judge Cooley has said that, in his opinion, the use of the vot-

ing machine "is a constitutional right of the people," since it assures the voter of absolute security as no other system can. Mr. Keiper, of the Patent Office, says, "It is the last and best contribution of science to good government." In this verdict, by the adoption of laws permitting its use, the States of New York, Michigan, Minnesota, Ohio, Massachusetts, California, and Rhode Island, and perhaps others, concur. In those States in which these laws are properly constructed, as in New York, for example, the cities and towns are permitted to experimentally employ the machine selected, and, if found satisfactory, later to adopt it and purchase such as may be needed, with a restriction as to the number of voters served by a machine. The commission which is intrusted with the duty of inspection, and of approval of machines of proper construction in that State, must consist of three persons, appointed by the Governor, of whom "one shall be an expert in patent law and two shall be mechanical experts." The members now serving are members of the American Society of Mechanical Engineers. This commission reports to the Secretary of State on each machine passed and adopted by them after examination, substantially as follows, these being the statements made relative to the machine here under discussion, for example:

"*First.* The machine is, in their opinion, adapted to register, under reasonable conditions, the vote of six hundred (600) voters within the hours allowed by law for holding an election.

"*Second.* The machine is capable of doing this work accurately and efficiently.

"*Third.* The machine may be safely used for election purposes.

"*Fourth.* The machine is strong in its parts and reliable in its action. It permits the voter to select or mechanically indicate the candidates, individually, in groups, or in accordance with the party ticket before voting, and thereafter to change his selection at will. The registration is accomplished by the voter's own action in turning a key, but the voter, in turning back the key for the purpose of making a correction, returns the counter by his own action to its former position. As the voter passes out from the machine, the indicators and all crosses (X) are returned to their former position, and are not visible, and the machine is also locked. The machine may be adjusted to limit the voting of females or other classified or special voters.

"*Fifth.* These conclusions are based on the mechanical construction and arrangement of details, and not on the Letters Patent or claims contained therein."

The older and pioneer machines were, naturally, not perfect, and some embarrassment arose from their occasional failure; but there is to-day no difficulty in obtaining safe and satisfactory

The whole case may be summarized in a sentence: "The machines retain all the virtues and exclude all the vices of the old methods of balloting." Their use would be entirely justified, even though they involved a more costly rather than a much less expensive system. Their adoption is looked upon by your committee as promoting good politics, good morals, and good finance.

Referring to this system, some time since, when the whole country was agitated by the outrages perpetrated by traitorous politicians in a number of States, a well-known journal remarked, with justice, as it seems to me:

"It is just such a condition as now exists in Kentucky that forms the strongest argument in favor of voting machines. These are in use in several cities in the State of New York, possibly with the greatest success in Buffalo. Voting by machinery can be recommended to every State in the Union, and with particular reason to Pennsylvania and Kentucky.

About 250 of these machines are in use in the State of New York; but it is perhaps hardly necessary to say that New York is not one of the cities in which they have been adopted. Yet the largest number of them is to be found in Buffalo, the next largest city of the State, and where there has been, at times, serious infringement of public and private political rights. Of the first experiment the outcome, as reported at the time by a Buffalo paper, an extract from which I find in my scrap-book, was the following:

"In the elections on Tuesday 225 voting machines were used in this State, distributed as follows: Buffalo, 108; Rochester, 73; Utica, 26; Ithaca, 10; Albion, 5; Canisteo, 2; West Winfield, 1. Extra machines, held in reserve to meet accidents or other emergencies, are not included in the enumeration.

"High praises of the machines come from all quarters. They have met every promise of convenience to voters, speed in voting, automatic and instantaneous footings of the total number of votes cast for each candidate, and a promptness in announcing the aggregate result in a city or village proportioned to the quickness with which the returns from each district were conveyed to a central point and tabulated.

"In addition to their speed and accuracy the machines are so constructed as to make it impossible to cast a defective vote, to 'repeat,' or to commit any fraud or irregularity. On the score of guaranteeing to every citizen the exercise of the voting privilege, without risk of disfranchisement on account of blunders, the machines seem absolutely perfect. Their superiority to the official ballot in this respect is plain and striking, and is demonstrated by official records.

"All in all, the voting machine is one of the inventive triumphs of the age, and it is as sure, in the near future, to displace the printed ballot as steam has proven to be in putting out of date the stage coach and the packet boat."

Judge Cooley has said that, in his opinion, the use of the vot-

ing machine "is a constitutional right of the people," since it assures the voter of absolute security as no other system can. Mr. Keiper, of the Patent Office, says, "It is the last and best contribution of science to good government." In this verdict, by the adoption of laws permitting its use, the States of New York, Michigan, Minnesota, Ohio, Massachusetts, California, and Rhode Island, and perhaps others, concur. In those States in which these laws are properly constructed, as in New York, for example, the cities and towns are permitted to experimentally employ the machine selected, and, if found satisfactory, later to adopt it and purchase such as may be needed, with a restriction as to the number of voters served by a machine. The commission which is intrusted with the duty of inspection, and of approval of machines of proper construction in that State, must consist of three persons, appointed by the Governor, of whom "one shall be an expert in patent law and two shall be mechanical experts." The members now serving are members of the American Society of Mechanical Engineers. This commission reports to the Secretary of State on each machine passed and adopted by them after examination, substantially as follows, these being the statements made relative to the machine here under discussion, for example:

"*First.* The machine is, in their opinion, adapted to register, under reasonable conditions, the vote of six hundred (600) voters within the hours allowed by law for holding an election.

"*Second.* The machine is capable of doing this work accurately and efficiently.

"*Third.* The machine may be safely used for election purposes.

"*Fourth.* The machine is strong in its parts and reliable in its action. It permits the voter to select or mechanically indicate the candidates, individually, in groups, or in accordance with the party ticket before voting, and thereafter to change his selection at will. The registration is accomplished by the voter's own action in turning a key, but the voter, in turning back the key for the purpose of making a correction, returns the counter by his own action to its former position. As the voter passes out from the machine, the indicators and all crosses (X) are returned to their former position, and are not visible, and the machine is also locked. The machine may be adjusted to limit the voting of females or other classified or special voters.

"*Fifth.* These conclusions are based on the mechanical construction and arrangement of details, and not on the Letters Patent or claims contained therein."

The older and pioneer machines were, naturally, not perfect, and some embarrassment arose from their occasional failure; but there is to-day no difficulty in obtaining safe and satisfactory

constructions. The occasional failure or temporary disablement of a machine, where it occurs, will be vastly more than compensated by their security and accuracy, their speed in making returns, and their convenience. Under the Australian system, in the city of Ithaca, as reported to me by the city clerk, there were thirty-six (36) rejected ballots for governor in the autumn of 1898; in the election for mayor, before introducing the machines, there were seven such ballots; in the spring of 1898 there were forty (40) such for recorder and fifty-three (53) for justice of the peace; in none of the later elections, using the ballot machine, has there as yet been one lost ballot. Were the losses even as great, legitimately, as with the older system, the gain would be beyond estimation in the insuring of honest elections. The few machines which have been thrown out, after formal use, were all of now ancient types, and failed, not in their mechanism, but in plan—not providing a blank column for independent voting; this column is now always present in the modern machines, precisely as in the ballot of the Australian system; which system, in fact, the voting machine duplicates so far as adaptability and flexibility are concerned, and in its allowance of entire independence on the part of the voter, while it insures that the manipulator of ballot-boxes shall be shut out and tampering with the franchise by criminals made impossible at the polls.

The feeling of the voter familiar with the machine is well expressed by the remark of a "Yankee," quoted in a Massachusetts newspaper, after he has deposited his vote in this manner in that State:

"I have voted by every method in use for more than twenty-five years, and at first was strongly opposed to the new machine; but it now seems to me simpler than, and superior to, any other method of voting that I have known."

This, however, is the most insignificant of its advantages.

I have long been intending to write a paper, to be presented to the American Society of Mechanical Engineers, on this subject; for it is, in my opinion, one of the most important of existing aids to the establishment of a free and universal suffrage —which much-boasted and precious possession we have actually never yet secured to the citizen of these United States of North America—that has yet been discovered, and it is the duty, as well as the special province, of the members of this Society to

promote this improvement, as a matter of professional duty and pride no less than from patriotic motives. Our members can do a great and a good work in this direction. There are now a number of good machines, and there will be more presently, and there will exist no excuse for their not being adopted. Even as a matter of finance, we find that they are good investments, and often pay several times legal interest in their saving over the costs of the Australian system, now standard the world over. They do, in fact, constitute an improved Australian system, adding to the older form later and better devices, and supplementing primary virtues by other and hardly less important supplementary advantages. The system is thus an improved Australian system, which owes its existence to the genius and skill of the American inventor, mechanician, and engineer.

Mr. T. W. Hugo.—I have been inclined to doubt very much the accuracy of some of the statements made in the paper concerning the machine when in practical operation, not because I had any definite reason for so doing, but because I could not understand that the human-nature factor could be so far eliminated as to bring out the ideal conditions mentioned in the paper. Our population *—I shall have to speak locally as far as our conditions are concerned, and generally as far as the paper is concerned—is largely foreign born; they are good people, desiring to vote correctly, and in every way to conform to the spirit and laws of their adopted country as true naturalized American citizens, but they find considerable difficulty in marking their ballot as they want to. The best way found is to give them an exact facsimile, as to size and everything; this they could take home and study, and then, having that picture before them, they could vote as they wished to. Now, I am satisfied that that advance instruction could hardly be given with this machine. I wish the machine itself could have been brought here and exhibited. I would like to ask the authors to comment on the probable size of the voting booth; the problem of storage between elections; the necessity of testing the machine before election for accuracy of record. I hope the questions which have been put forward will be fully answered, because I can see that in the establishment of this system a great deal will depend upon having all those little points fully explained.

* Duluth, Minn.

Mr. Geo C. Henning.—I think it is a fact that wherever these machines have been used they have given unusual satisfaction. One of the main advantages is that the time required for voting with this machine is very much less than under the old method, and the votes are never spoiled. The ballots are always on hand, and sometimes, with the old system, they are not. In New York City many booths are stored in vacant lots after election, and by the time the next comes around they have been burned up or something else happens to them, and new ones have to be purchased and erected. So the voting booth is not always a matter of trifling expense. These machines must, of course, be stored in a proper place and kept in good condition, and they will then be good for service for a long time. It is not likely a city would allow expensive machines of this kind to be injured or destroyed; such acts are, in fact, declared to be misdemeanors. In regard to getting the voters to vote with the machines for candidates selected, it is a very simple matter. It is mechanically accurate. Each group of officers to be voted for is placed in one place on the face of every machine; names of municipal officers and county officers, State officers, and other higher officials are each placed in relatively similar positions. If you simply take a sheet of paper and perforate holes big enough to let the key pass through, then a man goes and turns the key in the exposed places through the holes in the paper; he will vote just the way you want him to. (Laughter.)

Mr. J. E. Sweet.—There is one feature which Mr. Henning did not explain fully, and that is about the room these voting machines take up when they are packed away. There are one or two that I am familiar with which, when they are taken down, can be packed away in a space about 3½ by 4 feet, and 12 or 15 inches in thickness. So it will be seen that a good many machines can be stored in a comparatively small space.

Mr. Henning.—Large booths are not required where these machines are used, for the reason that the voting is done so quickly with the machines that the actual space occupied is only one-third of what the booths necessitate, and the result is that the machines can be placed where voting booths of the present system could not possibly be accommodated. Several of these machines can be placed in a small shop, whereas the present booths are so large that not one could be put into a shop.

*Mr. James Hamilton.**—The discussion by Mr. Hugo raises some questions which we shall attempt to answer. The paper would have contained the information sought had it not been planned to exhibit a machine at the meeting.

When assembled for use, as shown in Fig. 468, the keyholes in the top row are almost 5 feet from the floor. From top to bottom the machine proper measures about 3 feet, and across from the tip of the entrance bar to tip of the exit bar about 9 feet. The bearing faces of the standards are about 2 feet 6 inches from the floor. The votometer (including standards) weighs about three hundred (300) pounds, and is stored in a box 72 inches long by 40 inches high and 8 inches thick, or may be packed in a padded canvas case of less dimensions. When in use, the votometer is placed across a corner of the polling booth, and a calculation based upon the above data as to dimensions will show that the space occupied is not excessive. In fact, the ordinary polling booth could house, during an election, four of these machines assembled for use, one across each of its corners.

With every votometer is provided for its protection a storage case. In the interim between elections the votometer is dismounted from its standards, and votometer and standards are locked away in the storage case. As shown in Fig. 469, the back of the votometer is provided with a hinged cover. Protected in this way there is no danger from dust, as Mr. Hugo apprehends there may be. Indeed, dust may stop a clock or a watch, but it will not prevent you from setting its hands. All you do in voting upon the votometer is to turn a key and set the index fingers of the registers, and dust would never prevent you from doing this. The mechanism of the votometer is set in motion by power applied from without, and it is neither delicate nor complicated, even though it might not stand the "sand" and "rust" test to which ordnance boards subject small arms. Moreover, the operating parts are made entirely of aluminum or sheet brass. The small space taken up by the storage case and its regular outline and uniform size permit many to be stored in a moderate space and insure them cheap and dry storage in some public building.

The danger of the votometer's being tampered with by the

* Author's closure, under the Rules.

party in power so as to necessitate "tests" has been mooted. Of course, the votometer is a machine, and may be intentionally and unlawfully dismantled and deranged. Such acts would be punished as are other unlawful acts, and the same precautions would be taken and the same deterrents would be applied as in the case of other crimes. That the votometer does not in itself combine means for its own protection argues nothing. In any view it is difficult to see how one party could derange the mechanism without inflicting injury upon itself, since the registers could not be assigned until all the nomination papers were filed. And a register can be tested in less than ten seconds by rotating the shaft of its actuating pinion. It seems to us that the ease with which such tampering could be detected, if attempted, and the readiness with which the responsibility could be fixed upon the official charged with the safe-keeping of the key to the storage case, would effectually prevent any attempts at deranging the mechanism. In Massachusetts the machine is sealed by the officials after election and kept sealed for thirty days. Photographs of the registers before and after the election furnish indisputable records of the readings.

The votometer costs $500. The number of clerks needed is not the same under the votometer system as under the Australian ballot system, though Mr. Hugo states it is. No clerk is needed to deliver or to receive ballots. At Northampton, Mass., the number of clerks was reduced from six to four in each of the seven wards. At $5 per clerk per day the saving in clerk hire for one election was $70. As soon as machine voting passes the experimental stage, the cost of printed ballots (which printing is necessary only as a precautionary measure) will be saved. At a legislative hearing the city clerk of Northampton, a city of seven voting precincts or wards, stated that the saving to the city by the use of the machines in the three elections held in the year 1900 (one for the adoption of a city charter) was over $300. But progress is not determined solely by considerations of the economy attained when economy is understood in the narrow sense of a cash gain. The benefits derived from good government are worth paying for, as is also the feeling which comes from knowing that you are not being cheated of them by surreptitious markings deftly made by a dishonest election officer using a piece of graphite fixed under a finger nail.

The matter of instructing voters in the use of the votometer

depends, like other instruction, upon the personality of the pupil —in this case the voter—as well as upon the subject taught and the system of instruction pursued. So long as we admit to the rights of full citizenship the illiterates of Europe dumped on our shores, so long we may expect to experience difficulty in introducing new and better methods of voting. One who knows no more of our government and institutions than to state before the naturalization court that "Sir Richa da Croka" is President of the United States, is not ready for the votometer—or any other —grade. But it requires hardihood—and a great deal of it—to say that difficulty in expressing his choice on the votometer would be experienced by any voter intelligent enough to pass understandingly upon the questions submitted at our elections. Most men are familiar with the use of keys and the operation of winding up a clock before the age of twenty-one. In any case it is the plain duty of every citizen to acquaint himself with the method of voting legally established, and thereby to prepare himself for the intelligent exercise of his rights of citizenship. Abundant opportunity for such preparation would be offered if found necessary.

Dr. Thurston has spoken of the laws of the various States. It seems to us that the fees prescribed for the examination of machines by the State Commissions ($150 to each member for each examination, or nearly $500 for an examination) might well be reduced. We do not contend that the compensation paid the members is too great, but that since the State is benefited, it should pay some of this expense and thereby promote progress in this art by relieving the inventor of financial burdens. A moderate fee sufficient in amount to deter the submission of frivolous inventions, or the frequent submission of a defective machine, should be exacted, and no more. This is the policy of the Federal Government in regard to patents. Some of the States, Massachusetts among the number, have found it difficult to reconcile voting by mechanism with the requirement of their State constitutions that the vote be by *written* ballot. The word "written" has been construed to include "printed." But of the seven justices comprising the Supreme Court of Massachusetts, to which the legislature submitted the question whether the constitutional requirement of voting by written ballot would be satisfied by voting by mechanism, only three answered unqualifiedly in the affirmative. Three justices answered unquali-

fiedly in the negative, holding that the ballots cast must be such as could be actually read, handled, and counted, one by one. The remaining justice held that while the constitutional provision would be met by voting by machinery, yet the machine must be such as would show the voter what his vote was and would record any failure to register, or any illegal voting accomplished. Such a machine could not give the secrecy of the Australian ballot system, but the justice held that the Constitution does not require a secret ballot. If a vote is challenged, secrecy is lost in both the Australian and the votometer systems. (The opinions are set out in full in the appendix to this paper.)

Since the above paper was written, an improved votometer has been submitted to and approved by the Massachusetts Commission. In this improved type the card delivery for independent voting is replaced by two rolls, one of which is spring-controlled, and by the rotation of the other, from which a web of paper is unwound, and wound upon the spring-controlled roll. By turning the key in any given section of the independent row the web of paper is exposed in that section, and by raising the exit bar the rolls are operated to wind up the web and expose a fresh surface. The whole machine is simplified, and sections designed and arranged for one kind of voting, as for "straight ticket" voting, may, by a slight change, be readily adapted to a different kind of voting to meet the requirements of the particular election. This elasticity of construction greatly increases the serviceableness of the votometer.

The Bardwell votometer has been used at three elections held in Northampton, Mass., a city of 18,000 inhabitants, and a registration of 3,100 voters. The city is divided into seven wards. Dr. Alfred Pearce Dennis, Professor of History, Smith College, Northampton, describes these three tests in an article in "Public Policy," Vol. IV., No. 22, page 326, Chicago, June 1, 1901. Speaking of the Massachusetts law, he says: "The Massachusetts election law is widely known throughout the country, chiefly because it prescribes an alphabetical arrangement of the names of candidates upon all official ballots. Obviously, such an arrangement imposes upon a ballot machine heavier requirements than a system which permits either 'straight ticket' or 'party column' arrangement."

Referring to the expedition with which returns were made, Dr. Dennis states:

"From the standpoint of expedition in securing returns, the merits of machine voting, as seen in the following table, are too obvious to admit of discussion:

	Special City Election, Aug. 28, 1900.	State Election, Nov. 6, 1900.	Annual City Election, Dec. 4, 1900.
Total vote cast	1,325	2,619	2,533
Propositions or candidates to be voted for	2	55	22
Turns of key necessary for casting full ballot	2	16	11
Total number of individual blanks cast	104	8,083	7,120
Blanks for uncontested officers	0	3,768	3,579
Average number blanks per ward for each turn of key	7½	72½	92⅞
Average time occupied by voter at machine	10 secs.	80 secs.	35 secs.
Capacity of machine for 10-hour election day	3,000	450	1,000
Time required for official return of entire vote	7 min.	25 min.	17 min.

"As will be noted in the accompanying table, two turns of the key were required for a full vote on the two propositions submitted to the people in the special election of August last. The returns from the seven wards of the city were in the hands of the city clerk within seven minutes after the close of the polls. In the state election of November 6th, the ward results and totals for presidential electors of the two principal parties were in the hands of the city clerk within seven minutes after the balloting had ceased. The official vote for all candidates was 'in' eighteen minutes later.

"As regards the time element, another interesting consideration has to do with the expedition afforded by machines to the elector in recording his choice. From the Northampton trials, it was evident that the voter of average intelligence can indicate his choice on the machine in less time than he would occupy in the manual process of marking a paper ballot. It is to be added, however, that, while four or five men could be simultaneously occupied in as many separate booths in the preparation of their ballots, only one man at a time can be admitted to a voting machine."

Of the capacity of the votometer, as shown by these elections, the same author writes:

"In the state election of November 6th, the task which confronted the elector on admission to the face of the machine was the selection of sixteen indications of preference out of a field of 54 candidates (exclusive of individual presidential electors) and one proposition. Without the aid of 'party column' arrangement, the voter requires for intelligent selection a considerable margin of time for deliberation. It required more than a minute for the average elector to record his vote, and the selection was ordinarily made in the nervous haste induced by the knowledge that the voter was being timed by a score of men impatiently waiting in line their turn at the machine. In wards two and three, where the vote was heavy, the capacity of a single machine was overtaxed at 400 votes for the ten hours. 'Forced draught' methods, of course, add to dispatch in handling the vote, but they do so at the expense of deliberation of choice and un-

doubtedly increase the number of individual blanks recorded. In this election, where men were compelled to stand in line from 15 to 45 minutes in order to secure an opportunity to vote in wards two and three, a heavy percentage of blanks were cast, the average number of individual blanks per ward for each turn of the key running as high as 78½. As seen by the table, the average number of blanks was lower, however, than in the municipal election of December 4th, in which two machines were employed in each ward and congestion absolutely prevented. The exceedingly heavy blank vote, both at the State and municipal elections, is not to be construed as valid evidence of the difficulty imposed upon the voter by the machines. Three thousand seven hundred and sixty-eight blanks of the total of 8,083 cast in the state election are chargeable to three offices, for which there were no opposition candidates, while in the municipal election more than half the blanks are represented in the vote on four uncontested offices.

"The vexatious delays experienced by the voter in the second trial of the machines developed a robust and vigorous school of machine voting critics. In compliance with what the economists call a *felt*, rather than a *real*, want, two machines were set up in each of the seven polling places in the municipal election of December 4th. It was then demonstrated that the extra machine was entirely superfluous in at least five out of the seven wards.

"The capacity of a Bardwell machine to meet the demands of all reasonable exigencies was illustrated in a variety of ways, notably in the ingenious devices employed to permit the 'splitting' of an electoral ticket, and also in the arrangement by which women who may vote for members of the school committee are prevented from voting for any other candidates. In the case of the presidential electors, it transpired that but one Northampton citizen, out of the 2,619 who actually voted, desired to vote for a combination of names differing from those found upon the party tickets. To meet this exigency the voter, by turning the key in the proper hole, received a card, which entitled him to deposit a complete list of electors of his own preparation."

But it is to be remembered that one political party being responsible for the adoption of the votometer, the opposing political party felt in duty bound to do everything in its power to prove voting by mechanism impracticable. With this object in view its "ward-heelers" crowded the polling booths with voters at a given hour. Without such preconcerted action there would have been no delay, no long lines of waiting voters.

On the matter of recounts Dr. Dennis remarks:

"The determination as to who was legally elected mayor in the recent municipal election in Worcester, Mass., [in which there was a tie vote,] turned upon the question of the validity of some three ballots, which, upon purely technical and formal grounds, are regarded by certain authorities as 'defective.' Such a source of error is entirely eliminated where machines are employed to mark, register, and count the votes.

"Of course, the factor of human fallibility enters the equation at the moment the dials are examined and the vote transcribed to tally sheets at the close of the poll. [Dr. Dennis forgets the art of photography.] In the case of the recent

Northampton municipal election, a silly rumor gained currency, shortly after the official announcement of the vote, that a mistake had been made by the election officers in 'reading off' the vote in Ward 6, which, if corrected, would reverse the result of the mayoralty election. A feverish demand was made for a recount, and petitions for the purpose having been secured from all the wards, a recount of the entire vote for mayor was ordered. The 'recount' amounted to this: The machines were solemnly unlocked and the figures upon the registration dials re-examined in the presence of a corps of officials and a crowd of eager partisans, whereupon it was found that the vote upon all the machines agreed exactly with the results announced within seven minutes after the close of the polls on election day."

The question of economy is disposed of as follows:

"The chief argument heard in Northampton against the permanent use of voting machines has been the argument of financial economy. . . . The initial cost of machines is also a stumbling block to the taxpayer. The so-called 'Votometer' is placed on the market at $500. The fourteen machines used in the last Northampton election would, at this rate, involve an outlay of $7,000.

"As has been noted, however, nine machines are competent to adequately handle Northampton's vote. As an offset to the cost of the machines, it is to be remembered that machine voting does away with the expense of providing printed ballots and admits of a very considerable reduction in the required number of paid election officials. From the trials conducted by the city of Northampton, it would appear that machine voting has safely passed the experimental stage, and that, as a natural and logical development of American election methods, it is destined, in time, to supersede the paper ballot system now in vogue."

No. 912.*

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS IN EUROPE—1900.

BY HENRY HARRISON SUPLEE.

(Member of the Society and Secretary of the Executive Committee.)

In view of the fact that a number of members of the American Society of Mechanical Engineers were expected to visit Europe during the summer of 1900, several invitations were tendered by European societies, and it was at first thought that a party of members might be formed to cross in the same steamship in a manner similar to that which had been found so successful in 1889. A thorough canvass of the membership, however, showed that it was impracticable to arrange a date which would be acceptable to all, hence it was decided to allow the various members to make their own plans for crossing, and arrange for a general gathering on the other side.

The following committee was appointed by the Council to represent the Society at the various functions abroad, and to conduct the necessary organization of the members who might visit Europe: Charles H. Morgan, *President;* Jesse M. Smith, *Vice-President;* William H. Wiley, *Treasurer;* James Dredge, *Honorary Member;* H. H. Suplee, *Member of Council,* Mr. Suplee being appointed Secretary of the Committee.

Mr. Suplee sailed in April, establishing his headquarters at the offices of the *Engineering Magazine*, 222–225 Strand, London, the various members being instructed to report to him upon arrival in London.

Invitations had been received from the Institution of Mechanical Engineers and from the Institution of Civil Engineers to attend their respective conventions in London, and also from the Société des Ingénieur Civils de France to send delegates to attend its meetings in Paris.

The Paris meetings were the first in point of time, and the

* Presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions.*

Council had appointed as delegates the members of the c m
tee above named. But two members of that committee
able to attend, Messrs. Morgan and Suplee, as .
and Wiley had not yet reached Europe, and Mr. D: f
it impracticable to leave London at that time.

The Paris meetings, which took place from June 15th to June 20th, were naturally closely bound up with the Exposition, but included also numerous social and special functions. On June 15th there was given a brilliant *conversazione* at the fine new house of the Société in the Rue Blanche, at which the delegates were formally received and presented to the president, M. Canet, at the same time renewing many pleasant acquaintances made with members of the Société who had visited the United States in 1893, as well as with the hosts of 1889. On June 18th a musical and literary *soirée* was given at the house of the Société, the entertainment including instrumental and vocal selections and recitations by artists of the Opéra, the Comédie Française, and other noted companies. This brilliant function, to which ladies were also invited, was especially notable.

Numerous specially conducted visits to various sections of the Exposition were provided, and the house of the Société was thrown open to the delegates, and the valuable assistance of the *secrétaire administratif*, M. Armand de Dax, and his staff placed at their service to enable various point of interest in Paris and at the Exposition to be visited to advantage.

Among the special social functions of the week must be mentioned the reception given to the visiting delegates by M. and Mme. Canet, on June 16th, at their magnificent residence in the Avenue Henri Martin.

The convention was closed with a banquet at the Hotel Continental on the evening of June 20th, which was largely attended.

Prior to the meetings of the Institution of Mechanical Engineers, which took place June 27th to 29th inclusive, plans were made for a general gathering of the members of the American Society of Mechanical Engineers, a number of whom had arrived in London, and communicated with the Secretary of the Executive Committee.

The Secretary had already been in ı pl t c
tion with Mr. Edgar Worthington, the ɔr y
tion of Mechanical Engineers, through .

We, the President, Council and Members of
The American Society of
Mechanical Engineers,
in full recognition of the hospitality extended to us by
during the past summer, hereby extend
this official acknowledgment.
Realizing the great international importance of the
Universal Exposition of 1900 and
fully appreciating the remarkable social and
professional courtesies so gracefully extended by your
Society during its brilliant progress,
The American Society of Mechanical Engineers
here records its sincerest thanks to the
Société des Ingénieurs Civils de France
for the
memorable period.
We take this as a welcome opportunity to record
our deep appreciation and hearty thanks.
For The American Society of Mechanical Engineers

FIG. 482.—TESTIMONIAL SENT BY THE SOCIETY TO THE SOCIÉTÉ DES INGÉNIEURS CIVILS DE FRANCE.

Institution most kindly placed the hall in the house of the Institution, at Storey's Gate, St. James's Park, at the disposition of the committee.

A meeting of a number of the members of the Society, together with the Executive Committee, was held at the house of the Institution of Mechanical Engineers on June 25th, at which the various invitations of the Institution were announced and the necessary communications made. At all of the meetings of the Institution of Mechanical Engineers the fact was emphasized that the members of the American Society of Mechanical Engineers were especial participants and honored guests. At the opening ceremonies of the convention prominent places were reserved for the Executive Committee and visiting members, and the President, Mr. Charles H. Morgan, was called upon to speak in response to words of greeting from Mr. E. Windsor Richards, who, in the absence of Sir William H. White, presided.

From a technical point of view, the most important visit of these meetings was that to the works of Messrs. Williams & Robinson, at Rugby, on June 29th. A special train on the London and Northwestern Railway carried the members of the two societies to Rugby, the train delivering the party directly at the works, where, under the courteous and hospitable guidance of Mr. Mark Robinson, Captain Sankey, Mr. Lazenby, and others, this fine works, admittedly one of the most modern in arrangement in England, was thoroughly inspected.

Other parties were made for boat trips up the Thames to Staines, and down the river to the docks, and all the visitors expressed themselves most highly appreciative of the privileges which had been offered them.

On the evening of Wednesday, June 27th, occurred the banquet at the Hotel Cecil, upon which occasion the American visitors were highly honored. Mr. E. Windsor Richards ably filled the chair, supported on the right by the American Ambassador, Hon. Joseph H. Choate, and on the left by the Right Hon. Lord Alverstone, Master of the Rolls, by whose side was placed Mr. Charles H. Morgan, President of the American Society of Mechanical Engineers, other members of the Executive Committee and of the Society being similarly placed by the side of distinguished British hosts. The occasion was a memorable one in many ways, and undoubtedly served to unite

To the President, Council, and Members of the
INSTITUTION OF MECHANICAL ENGINEERS,
Greeting:
We, the President, Council, and Members of the
in earnest appreciation of the WARM HOSPITALITY
extended to us by your Institution, do hereby extend this official
acknowledgment.
Not only by the distinguished manner in which the American
visitors were included at the recent professional sessions of
your Institution, but also because of the hearty and cordial hos-
pitality extended at all the social functions of the occasion, was the
meeting of the
made
memorable to us.
Coming at a time when INTERNATIONAL TIES were doubly
strong, because of stirring events in other parts of the world,
these occasions of reunion and friendship between men of one blood
and one profession have renewed and strengthened the bonds
which everywhere unite men of the English-speaking race.
Therefore, seeing in your brilliant hospitality and notable
reunions the expression of spontaneous good-will and fellow-
ship toward the members of our Society; and still further perceiving
in it powerful evidence of the
of thought and
action between ENGLAND AND AMERICA, we feel ourselves
deeply honored in expressing for our Society the high appreciation
which we feel
Accept therefore this official expression as but the formal state-
ment of a heartfelt greeting, with wishes of happiness and pros-
perity; personal, professional, and national.
For the American Society of Mechanical Engineers

FIG. 483.—TESTIMONIAL SENT BY THE SOCIETY TO THE INSTITUTION OF MECHANICAL ENGINEERS OF ENGLAND.

more closely than ever the professional and personal ties existing between the two societies.

Too much cannot be said of the manner in which the Secretary of the Institution of Mechanical Engineers, Mr. Edgar Worthington, exerted himself to render all the events most enjoyable and agreeable to the American visitors, and in this he was most ably seconded by the members of the Reception Committee, headed by Mr. William M. Maw, its chairman, since elected President of the Institution, and by many individual members of the Institution.

The meetings of the Institution of Civil Engineers took place from July 2d to July 6th inclusive, and prior to that date the Secretary of the Executive Committee had been in communication with the Secretary of the Institution, Dr. J. H. T. Tudsbery, whose courteous services are most gratefully acknowledged. Invitations for all the functions of the convention were placed in the hands of the Executive Committee with care and promptness, and every possible facility afforded for their distribution.

The opening meeting was held on the afternoon of July 2d, at the house of the Institution in Great George Street, Westminster, where the American visitors were greeted by an address of welcome by the President, Sir Douglas Fox. At this meeting, not only members of the American Society of Mechanical Engineers were present, but also members of the American Society of Civil Engineers, the American Institute of Mining Engineers, and the American Institute of Electrical Engineers.

Sir Douglas Fox said, in part:

"This Institution is the home of the Parent Society of British Engineers. It is cosmopolitan in this sense, that it includes every class of Civilian Engineer, and that is the meaning from our point of view of the words 'Civil Engineer.' Now, the great advantage of that for you and for us on the Council of this Institution is, that I have this afternoon the honor of being supported on this platform by representatives not only of my own Council, but of that of the Mechanical Engineers who have been your kind hosts during the last week, of the Electrical Engineers, of the Naval Architects, and of the Iron and Steel Institute. I have only got to mention those names to you to show you that on this occasion I represent a very great force, not only in this country, but throughout the world. There are men here who have made their mark, as there are men on the other side, facing me, who have made a very great mark upon the world; and it is good for us to come and see one another face to face on an occasion like this. Then, on the other hand, because we are cosmopolitan, we have been able to extend our invitation not merely to the Society of Civil Engineers of America,

To the President, Council and Members of the
Greeting:
We, the President, Council and Members of
The American Society of Mechanical Engineers,
in full recognition of the hospitality extended to us by your Institution during the past summer,
hereby extend this official acknowledgment.
Realizing the profound
included in the reception by the INSTITUTION OF CIVIL ENGINEERS of their American
professional brethren
And fully appreciating the remarkable social courtesies so gracefully extended, we here record
the sincerest thanks of The American Society of Mechanical Engineers.
We take this as a welcome opportunity to record our deep appreciation and hearty thanks.

FIG. 484.—TESTIMONIAL SENT BY THE SOCIETY TO THE INSTITUTION OF CIVIL ENGINEERS OF ENGLAND.

of which some of us are very proud to be members, but also to members of the other engineering societies, the Mechanical Engineers, the Mining Engineers, the Electrical Engineers, and the Naval Architects of the United States, and we hope that all those bodies are more or less represented amongst us this afternoon."

Responses were made by Col. H. S. Haines, member of the Council of the American Society of Mechanical Engineers, and by Mr. Jesse M. Smith, Vice-President of the American Society of Mechanical Engineers, after which a general *conversazione* followed.

On the following day occurred the most notable event of the convention, a trip to Windsor Castle, where by special permission of her late Majesty Queen Victoria the private apartments of the Royal residence were thrown open to the visitors, after which a luncheon was served in the conservatory, the Institution of Civil Engineers and its American guests being the guests of the Queen.

The party was then gathered on the lawn, to be received by Her Majesty, who drove before them, and caused to be presented to her by Sir Douglas Fox, the President of the Institution of Civil Engineers, Mr. John J. Wallace, President of the American Society of Civil Engineers, and Mrs. Wallace; Mr. Charles H. Morgan, President of the American Society of Mechanical Engineers, and Mrs. Morgan; and Mr. Charles Hawksley, of the Institution of Civil Engineers, and Mrs. Hawksley. The Queen spoke a few words of welcome, saying: "I am very glad to see you here, and that you have had such a beautiful day," and then drove slowly down the line, bowing a greeting to the entire party.

The Fourth of July was left without special assignment, in order that the Americans might celebrate their national holiday according to their own plans, and many most enjoyable reunions took place during the day and evening.

On the evening of July 5th occurred the reception by the President and Council of the Institution of Civil Engineers, at the Guildhall, where a large attendance of ladies and gentlemen made the occasion memorable.

On July 6th there was an excursion to Warwick and to Stratford-on-Avon, a special train taking the party first to Warwick, where they were welcomed by the Earl and Countess of Warwick at the Castle, and by them shown through the stately buildings so rich in historical reminiscences and relics, after

which the whole party was entertained at luncheon in a large *marquée* which had been set up for the purpose in Warwick Park. A hurried run to Stratford followed, and after doing homage at the tomb of Shakespeare, the visitors were brought back in their special train to London, bidding their hosts farewell upon the platform at Paddington Station.

At the preliminary meeting, held in the hall of the Institution of Mechanical Engineers on June 25th, an invitation was extended to the American visitors by Messrs. Ludwig Loewe &

Messrs Ludwig Loewe & Co.
AND TO
Herr F. Loewe, Berlin
GREETING:

FIG. 485.—TESTIMONIAL SENT BY THE SOCIETY TO MESSRS. LUDWIG LOEWE & CO. AND TO HERR F. LOEWE, BERLIN.

Co., through their London representative, Mr. H. F. L. Orcutt, member of the American Society of Mechanical Engineers, to visit Berlin as the guests of the company. A number of the members accepted this most hospitable invitation, and although it was impossible for the Secretary of the Executive Committee to be among the number, he has heard most glowing accounts of the trip and the entertainments from those who were so fortunate as to be present.

It would be invidious to make any comparison between the occasions of 1900 and those of 1889. The writer, who had the great privilege of being present and active on both occasions, feels that they were so entirely different as to render compari-

sons impossible. In 1889 the formation of a complete party in America, crossing on a special steamer and effecting a coherent organization on shipboard, gave a unity to the affair which no independent system could produce.

At the same time the meetings of 1900 included events which were unique in themselves. The day at Windsor, with the reception by Queen Victoria, was, socially speaking, above anything occurring in 1889, while the active entrance of American competition into European engineering industries gave a new meaning to all that was seen and heard. Both occasions were memorable; both will long be remembered by those who were so fortunate as to participate in them; while for those who, like the writer, had the rare privilege of participating in the detailed work of entertainment with our British and French hosts, the deep and lasting friendships created by the events can only be hinted at, as being beyond mere verbal expression.

The following list of members of the American Society of Mechanical Engineers participating in the European events of 1900 does not profess to be complete, owing to the neglect of some to register at the office of the Secretary of the Executive Committee. Every attempt has been made to complete it, and under the circumstances it may be considered as reasonably correct and full.

Almond, T. R.	Greenwood, P. F.	Reed, W. E.
Archer, E. R.	Haines, H. S.	Robinson, A. W.
Baker, C. W.	Hayward, H. S.	Sancton, E. K.
Barnaby, C. W.	Henning, G. C.	Sheldon, F. P.
Braine, B. G.	Honiss, W. H.	Smith, Jesse M.
Breckenridge, L. P.	Howe, H. M.	Smith, Oberlin.
Brown, A. T.	Hunt, R. W.	Spangler, H. W.
Bullard, E. P.	Hunter, G. E.	Stiles, N. C.
Carroll, L. D.	Jones, W.	Suplee, H. H.
Colby, A. L.	Kuwada, Gompei.	Swasey, A.
Cooke, H.	Loss, H. V.	Thomas, C. W.
Dickie, G. W.	Low, F. R.	Thomson, J.
Doran, W. S.	Melvin, D. N.	Ward, C.
Dredge, J.	Miller, F. J.	Webster, W. R.
Fisher, C.	Miller, S.	Wheeler, H. S.
Flad, E.	Norbom, J. O.	Wheelock, J.
Freeland, F. T.	Parks, E. H.	Wiley, W. H.
Goss, E. O.	Parsons, H. deB.	Wood, K.

Upon the reunion of the Executive Committee in the autumn in America it was decided to recommend to the Council that

illuminated testimonials be drawn up and executed for transmission abroad. The Council approved this recommendation, and directed the Executive Committee to prepare suitable resolutions and have these transmitted to the Institution of Civil Engineers, London; the Institution of Mechanical Engineers, London; La Société des Ingénieurs Civils de France, Paris; Messrs. Ludwig Loewe & Co., Berlin.

This was done, and reproductions of the illuminated testimonials are given herewith.

These have been most heartily acknowledged and given conspicuous places in the houses of the various societies.

No. 913.

MEMORIAL NOTICES OF MEMBERS DECEASED DURING THE YEAR.

GEORGE H. NORMAN.

Mr. George H. Norman's name appears on the list of life members of the Society issued in its first catalogue in September 1880. He was born in Newport, R. I., in 1827, and achieved his notable success without the advantages of special training for professional work which have come within the reach of the younger practitioners. He was first interested in journalistic work, but abandoned this pursuit to undertake gas-works construction. These were generally built for private owners, Mr. Norman receiving his compensation in profitable investments in the companies themselves. From this the step was easy to a similar investment in water-works companies, of many of which he was a dominating force. His methods of financiering were later extensively followed by other contractors, but in New England especially Mr. Norman became a controlling personality in this particular field. His keen judgment as to the probable future growth of the community, and his foresight in purchase of available sources of water-supply made his companies profitable, and were the basis of his considerable fortune. He was for many years a member of the American Society of Civil Engineers, and created the fund for the conferring of the Norman Medal in that Society. He died at Palm Beach, Fla., on February 4, 1900.

FRED W. WOOD.

Mr. Wood's life was one of those which illustrate forcibly the possibilities which are open to him who determines to succeed, spite of all obstacles, and lives up to his determination. He was born April 28, 1853, in Prairie du Chien, Wis., his father being Dr. E. P. Wood, who was colonel of the Seventeenth Illinois Regiment during the Civil War. At the conclusion of the war the family moved to Kansas City, where the son entered the

high school, from which he was graduated, and whence he went to the University of Michigan. Before completing his course at the University, he left and took up field work in civil engineering and surveying, working on the Chicago and Northwestern and the Kansas City and Memphis railroads, and in the office of the City Engineer at Kansas City. In 1874 he went to Los Angeles, engaging in editorial work, and also forming a connection with Mr. Prudent Beaudry, which led in later years to his selection as executor and manager of the great Beaudry estates.

Mr. Wood was connected at various times with the Lake Vineyard Land and Water Company, the Abstract Title Insurance Company, and the San Gabriel Winery in important positions.

While managing the Beaudry property he handled the affairs of the Temple Street Cable Railway, and was led to make a careful study of street railroad problems and running. His success was so marked that in 1895 he was offered the position of Manager of the Los Angeles Railway Company, which he accepted and held during the remainder of his life.

Mr. Wood was a man who gained and kept the respect and friendship of his workmen, his associates, and his employers. He was prominent in the business and social life of Los Angeles, and was a member of many societies of a social nature, and of the American Society of Civil Engineers, as well as of this Society, which he joined in May, 1892. Although for many years gradually failing from consumption, he kept manfully to his work, preferring to die in the harness rather than to prolong his life in idleness, until the end came on May 19, 1900.

LOUIS IRVING SEYMOUR.

The South African War has not only brought sorrow to the homes of England, but has struck down as well many of the best of America's sons, among whom is Major Seymour. Born at Whitney Point, N. Y., on December 23, 1860, he received his education in the village schools, and when seventeen years old began work in the machine shop of John Cotter at Norwalk, where he remained for three years. He intended to enter the navy, and passed the examinations for Annapolis, but found that his age was a few weeks above the limit, and was forced to relinquish his hope of a seafaring life. From 1881 to 1884 he worked for the Lackawanna Iron and Coal Company, and then went to

Venezuela to erect a mill engine at the El Callao Gold Mine, for the Dickson Manufacturing Company. From this time on his life was largely devoted to mining development and management. He remained at El Callao Mine as mechanical engineer until 1886, when he returned to this country and married Miss Kate Perry, of Whitney Point, who survives him. For a time he was with the Washington Cotton Mills, and afterwards with the Plymouth Cordage Company; but his interest was in mining, and in 1890 he went to Kimberley, South Africa, as chief mechanical engineer for the De Beers Consolidated Mines. In 1893, while still retaining his connection with the De Beers Company, he went to England and took charge of the works of Fraser & Chalmers, Limited, at Erith, to superintend the construction of machinery for the Transvaal and Cape Colony Mines, a work which lasted until 1896, when he returned to South Africa, locating at Johannesburg as mechanical engineer to H. Eckstein & Co. and the Rand mines. Here he became, by reason of his ability and fidelity, the most trusted adviser of the companies on all mining and mechanical matters, as well as on the administrative and executive side. The results of his work are seen in the well-adapted plans and arrangement of all the Johannesburg mines.

After the breaking out of the war he proposed the organization of the "Railway Pioneer Regiment," to assist the Royal Engineers in repairing damage done to bridges and railways, and it was largely through his efforts that the organization was effected. While serving with this regiment, of which he was second in command, he was killed at the Zand River, Orange River Colony, on June 14, 1900. In memory of his service to the mining industry, the "Seymour Technical Library" is being established by his friends, who feel that such a memorial is an appropriate one for a man who, though originating many new devices, always wished to allow others to use them.

He became a member of the Society in May, 1892.

WINTHROP THAYER.

Mr. Thayer was born in Boston, November 23, 1863, and was one of a family of seven children of Mr. Charles F. Thayer, who was also born in Boston. Mr. Winthrop Thayer entered the public schools of that city, and remained in them until about

nineteen years of age, when he entered the employ of Upham, Tucker & Co., in the dry goods commission business. He remained with this firm for a period of two years, when he left it and entered the mechanical field, in which he was always very much interested, taking a position with the Babcock & Wilcox Company in their Boston office. He remained with them for five years, during which time he secured a very extensive knowledge of mechanical and engineering subjects through persistent and untiring efforts and study. He then entered the employ of the Wainwright Manufacturing Company, to take a position as assistant superintendent at their works in Medford, Mass. He remained at these works for about two years, when he reëntered the employ of the Babcock & Wilcox Company, this time taking the position of general manager of their New England business, with office in Boston. He remained in this position up to July 1, 1895, when he started the concern of Thayer & Company, Incorporated, who embarked with the Aultman & Taylor Machinery Company, of Mansfield, O., in the manufacture and sale of horizontal and vertical water-tube boilers.

Mr. Thayer was President of Thayer & Company, Incorporated, at the time of his decease, which occurred in Boston on July 18, 1900, as the sequel of a series of illnesses and accompanying complications which started in January in the City of Mexico, to which place he had gone upon a pleasure trip. He had a remarkably wide acquaintance, particularly in Boston, and was a member of many of the social organizations there, among them being the Algonquin Club, Exchange Club, Boston Athletic Club, Newton Club, and New England Cotton Manufacturers' Association; he was also a quite prominent yachtsman, being Vice-Commodore of the Hull (Mass.) Yacht Club.

JAMES HEMPHILL.

Mr. Hemphill was born July 22, 1827, at Mechanicsburg, Pa. He served an apprenticeship at the forge, and in 1850 entered the employ of the Pittsburg Waterworks, staying with them until he had risen to be their engineer. After trying several branches of mechanical industry, he became associated, in 1859, with H. F. Hart and the late W. S. McIntosh in the management of a shop which gradually grew into the Fort Pitt Foundry.

Mr. Hemphill was among the early advocates of the successful reversing blooming-mill for steel working. Many mills had previously failed because of lack of mass and strength; the ones which he built and installed at the Pittsburg Bessemer—afterwards the Homestead—Works of the Carnegie Steel Company succeeded, and were the models for all later mills. The success and fairness of his management are shown by the fact that his establishment, in its long career, never had a strike or serious difficulty with the workmen.

He joined the Society in May, 1884, and was also a member of the Institute of Mining Engineers. He died August 7, 1900.

JOHN F ALLEN.

Mr. Allen was born in England in 1829. When a boy of twelve years he was brought to this country, and presumably went into the machine and engine business, as we find him in an engine-room in New York in 1860, where he had been recommended by Messrs. Thurston Gardner & Co. as the best engineer whom they knew to remedy some trouble that had been found with one of their engines. During that year he met Mr. Charles T. Porter, and explained to him the mechanism of a valve motion which he had invented while running the engines on the "Curlew," and which was designed to overcome the difficulties of the Corliss motion. Mr. Porter took up the matter and combined the valve with the Porter governor, thus enabling the running of engines at high speeds and with good economy. Until 1873 Mr. Allen was associated with Mr. Porter in the engine business, and also invented an inclined tube vertical water-tube boiler, which was very successful. After that time he devoted himself to the manufacture of air compressors and of pneumatic riveters, doing a small business in New York City until the time of his death on October 2, 1900. He was a charter member of the Society.

JAMES H. BOWDEN.

From the coal region of Cornwall, England, at Penzance, where he was born in 1846, Mr. Bowden was brought to the coal region of Pennsylvania at Tamaqua, when he was but a child, and the coal-mining industry became the interest of his life. He was apprenticed to Carter & Allen at the machinist's

trade, afterwards going to Philadelphia, where he attended a technical school and worked in shops in the city. In 1869 he went to Wilkesbarre as superintendent of the Wyoming Valley Shops, in which work he remained until the formation of the firm of Stearns & Bowden for general engineering practice in 1872. This firm was not long-lived, since in 1873 Mr. Bowden accepted a position as chief engineer of the Susquehanna Coal Company, a position which he later took for all the coal companies of the Pennsylvania Railroad. This position he held at the time of his death, as well as that of borough engineer of Nanticoke, the latter having been held since the incorporation of the city.

Mr. Bowden held several patents, the most notable being one for the Bowden self-oiling car-wheel, now extensively used in the coal regions. Shortly before his death he finished a history of the coal mining industry from the first shipments to the year 1900, which history will be published in the history of the Pennsylvania Railroad. He was a man whom it was good to meet, and enjoyed sport as well as labor. A wife and three children survive his death, which took place from internal trouble on November 16, 1900. He has been a member of the Society since November, 1891, as well as of the Institute of Mining Engineers.

CHARLES A. DIXON.

Mr. Dixon was born in Newburgh, N. Y., March 8, 1856. He began his education in the schools of that place, but upon the death of his father, when he was still young, which event left him alone with his mother, he changed the schoolroom for the shop, entering the employ of Whitehill, Wood & Co., at fifteen years of age, as an apprentice. After finishing his apprenticeship as a pattern maker, he passed through the machine shop to the draughting-room, and took up the study of engineering under Mr. Edgar Penney, one of the Society's members, who was at that time superintendent for the company. Mr. Dixon advanced so rapidly that when Mr. Penney resigned in 1878 he succeeded to the position of superintendent, which position he held until 1892, when he became associated with the Higginson Plaster Works. He spent the greater part of the next year in France in the interests of this company, but left them in 1893 to establish, in company with Messrs. Gardner Van

Ostrom and Homer Ramsdell, the Dixon Steam Engine Works for the manufacture of Corliss engines and general machinery. This firm did a large business, installing among other large plants the engines and piping in the power house of the Steinway Railroad Company at Astoria, L. I. On the death of Mr. Van Ostrom, in 1894, the business was closed, but in 1895 it was reorganized and combined with the Wright Steam Engine Works to manufacture both Wright and Dixon-Corliss engines. Mr. Dixon was superintendent and general manager of the combined companies until 1899, when he resigned the position to open an office, in connection with his son, as consulting and contracting engineer.

On December 17, 1900, he slipped on the car track and fell, breaking his elbow and receiving such a shock that meningitis set in, resulting in his death on December 22d.

Mr. Dixon worked his way up from small beginnings to a large degree of success. He had been a member of the Society since May 21, 1884, and was well known among steam-engine builders. He was as well an honorary member of the Association of Stationary Engineers, and a Mason of high standing, being a member of Mecca Temple, No. 1, of the Mystic Shrine.

MELLEN S. HARLOW.

Mellen S. Harlow, late manager of the New England branch of the Ingersoll-Sergeant Drill Company of New York, was born at East Hebron, Me., October 17, 1860. He received his early education in the public schools of Maine, and taught school before completing his high school course at Cape Elizabeth. Soon after his graduation he entered Stevens Institute of Technology, which he attended for about three years.

After leaving school he worked on the Croton Aqueduct, and being interested in the operation of the Ingersoll-Sergeant drills, he became a salesman for the company, and ran the drills at many places, thus gaining a practical knowledge of them.

In October, 1887, he opened a small office in Boston for the company, and worked in New England as his territory singlehanded until 1893, when he represented his company in South Africa. Before going to that country he applied for member-

ship to the American Society of Mechanical Engineers, and was accepted.

Returning from there, he again took charge of the Boston office, which position he held until his death, of typhoid fever, which occurred at his home in Malden, Mass., December 29, 1900.

ALEXANDER HENDERSON.

Commodore Alexander Henderson, United States Navy, who died at his home in Yonkers, N. Y., January 12, 1901, was born in Washington, D. C., on the 12th of July, 1832. He was the son of the late Col. Thomas Henderson, United States Army, and grandson of Commodore Thomas Truxton, United States Navy.

Mr. Henderson entered the navy as an engineer officer, February 26, 1851, served through the several grades with honor and distinction, at sea and on shore, during war and peace, and became chief engineer in June, 1861.

His first sea service was on board the steam frigate "Susquehanna," with Commodore Perry's fleet on the coast of Japan in 1855; afterwards he served in various vessels on the several stations, including service with the Paraguay expedition in 1858, and as fleet engineer at different times of the Mediterranean and Asiastic stations.

During the Civil War he was continuously employed, and saw much hard service with the blockading fleets, ending with his duties on the James River at the siege of Petersburg and the fall of Richmond.

Commodore Henderson was conspicuous as the engineer member of the Naval Advisory Board from 1884 to 1888, which Board had been authorized, by act of Congress, to prepare plans for, and supervise the building of, the first of the vessels for the new navy. The machinery for these vessels was designed by Henderson, and erected under his inspection and direction. The successful cruises of the "Chicago," "Atlanta," "Boston," and "Dolphin" since their first appearance for active service add much to the credit of this distinguished naval officer as a practical constructor and mechanical engineer.

Commodore Henderson, having been at the head of his corps for over two years, reached the retiring age on July 12, 1894, and was then placed on the retired list with the rank of commo-

dore. Being at this time in the enjoyment of excellent health, he busied himself in establishing his sons in business in New York City, which undertaking was eminently successful.

At the declaration of war with Spain, in 1898, Commodore Henderson immediately volunteered for active duty, and was ordered as fleet engineer of the auxiliary navy, where he performed valuable service until the close of the war.

He was twice shipwrecked and had yellow fever in foreign ports three times, yet was active and rugged until the year preceding his death. He was a man of marked executive ability, quick in decision, ready in resource, and with a thorough knowledge of his profession; and, since he early gained high rank, exerted a commanding influence in the Navy Department for a long period. His connection with the Society dates from May 27, 1885.

Alexander Henderson has been known, since his youthful days in the navy, throughout the service and with friends connected with the workings of the Department, as Sandie Henderson, a devoted husband and father, a genial gentleman, faithful, distinguished, and a meritorious officer, whose family and host of friends can hardly realize that his place among us on this earth is vacant for all time.

WILLIAM McMANNIS.

Mr. McMannis was born on the 15th day of November, 1842, in Westfield, N. J. He attended the high school at Newark, N. J., but left it to enter the Rock Island Machine Works, where he remained from 1857 to 1861; he then entered the draughting-room at the same place, and remained until 1863, when he took a position at Fortress Monroe, Va., in charge of the power plant of the post, and the shops for the repair of government steamboats and like work. Here he remained until 1872. Mr. McMannis then came to New York and was appointed chief engineer for the New York Hotel and the Trinity Building, for both of which he superintended the installation of the elevators and heating plants, this occupation taking up his time until 1874. From 1874 to 1888 he was in charge of the Union Club Building and of the New York Academy of Music, installing the heating and elevator plants in both places.

In 1888 Mr. McMannis was appointed chief engineer to the Board of Education of New York City, which position he held

at the time of his death, January 19, 1901. In this position he made all the plans and specifications for heating and electric lighting in the public schools in New York City, and superintended the construction of this work. Up to the time that Mr. McMannis took charge of this department at the Board of Education, the heating work done in the public school buildings was of the most primitive character, not extending beyond the simplest method of direct heating, and practically no attempt being made to ventilate the schoolrooms.

Mr. McMannis, in conjunction with Mr. Snyder, the Superintendent of Buildings, Board of Education, at once undertook to improve on the old methods, and gradually and continuously improved the character of the heating and ventilating apparatus introduced into the public schools. Proper ventilating apparatus was a special feature of all his plans, and at the present time the public schools in New York City are all well heated and well ventilated, and the credit for the work done and now being done belongs, in a large measure, to Mr. McMannis. He deserves especial credit, as he was a man who had only a common-school education and graduated from the ranks of operating engineers.

Mr. McMannis joined the Society in June, 1894.

EDWARD CHARLES DARLEY.

Mr. Darley was born at Tarrytown, N. Y., January 28, 1846, and was a son of William George Darley and Mary Esther Weeks Darley. His education was obtained in the schools of Warren, O., and Pittsburg, Pa. Before his twentieth year he was employed as civil engineer on the New Castle and Beaver Valley Railroad, and located at New Castle, Pa. Prior to this time, however, he joined the One Hundredth Pennsylvania Volunteers, and served in what is known as the "Famous Roundhead Regiment." In 1866 he went to Brazil, Ind., to build a blast furnace, and in 1867 to St. Louis, Mo., where he followed his profession of mechanical engineering and building blast furnaces until 1887, when he was called to Ashland, Wis., to build a large blast furnace which took him some time. Finishing there in 1888, he went to Portland, Ore., to build a large blast furnace, and in 1889 returned to Pittsburg, Pa., where he was employed with J. P. Witherow as general superintendent of

blast-furnace construction until 1892. After this he practised mechanical engineering until 1897, at which time he, together with Mr. S. C. Munoz, became general Western agents for the Aultman & Taylor Machinery Company, of Mansfield, O., manufacturers of Cahall water-tube boilers. He succeeded to the firm of Munoz & Darley in 1900, Mr. Munoz retiring from the firm. Between the years of 1866 and 1897 Mr. Darley built a total of forty-four blast furnaces, steel plants, and rolling mills. He was a member of a number of engineering societies, and a charter member of the American Society of Mechanical Engineers.

Mr. Darley's life has been one of untiring activity, and his efforts have been crowned with a high degree of success. He has travelled throughout the United States from coast to coast, and has a large circle of friends. He was married January 12, 1869, to Miss Mary Elnora Watson. His widow and one son, William W. Darley, survive him. Mr. Darley died in Chicago, February 16, 1901.

GEORGE H. STARBUCK.

Mr. Starbuck connected himself with the Society at its Pittsburg meeting in 1884. He had been recently appointed (1882) by President Arthur to the position of Supervising Inspector of Steam Vessels for the Second District, extending from Philadelphia, Pa., to Portland, Me., with headquarters in New York City, a position whose duties he continued to discharge until prevented in January of the current year by the increasing disabilities from his state of health. He passed away in Troy, N. Y., on March 7, 1901.

He was a graduate of the Rensselaer Polytechnic Institute of Troy, and was for over twenty-five years a member of the firm of Starbuck Brothers in that city, of which firm he was the junior of the three. For many years they did the largest steam engineering business in the State outside of New York City, including the manufacture of the Osgood dipper dredge, and the engines of many tugs still in operation on the Hudson River. The Tompkins Market iron building in New York is one for which they were contractors when iron building was more of an untried field than it has since become. During the war of 1861–65 his firm turned out large quantities of shot and shell. The firm as such met with some peculiar misfortunes, and its business went to ruin.

He was seventy-eight years old at the time of his death, which was the result of a complication of diseases running over several years.

ASHLEY B. TOWER.

Mr. Tower, born in Dalton, Mass., in 1847, began his professional work at an early age in the office of his brother, D. H. Tower, in Holyoke. After eight years he, in 1878, formed a partnership with his brother, which was continued until 1889, the firm meantime building and reconstructing many mills of all kinds throughout New England, designing fifty-five mills for Holyoke alone, and being consulted in regard to nearly as many more. In 1889 Mr. D. H. Tower retired from the firm, and the work was carried on alone by Mr. A. B. Tower until Mr. J. H. Wallace was taken into partnership. In 1897 the offices were removed to New York, and the business continued to grow. The firm designed a number of very large plants, among them being the one at Rumford Falls, Me. In January, 1891, Mr. Wallace withdrew from the firm, and Mr. Tower carried on the business until the time of his death, which occurred unexpectedly at his home in Montclair, N. J., on July 8, 1901. Mr. Tower was the leading designer of paper mills in the country, was for many years consulting engineer of the American Sulphite Company, and was a prominent civil engineer. He was a member of the American Society of Civil Engineers, the Canadian Society of Civil Engineers, and of many Masonic lodges and societies. His connection with the American Society of Mechanical Engineers dates from his coming to New York in December, 1897.

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NOTE.

1. For authors of papers and for the names of debaters upon them SMALL CAPS are used.

2. *Italic type* is used for the full titles of papers. Cross references to the subject of a paper which may not be its exact title are in Roman type, as are the titles under the caption of the author's name.

3. The Society is not responsible as a body for the statements of fact or opinion in its papers and discussions.

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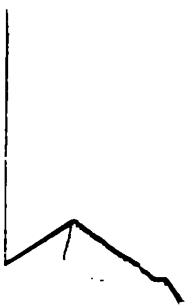

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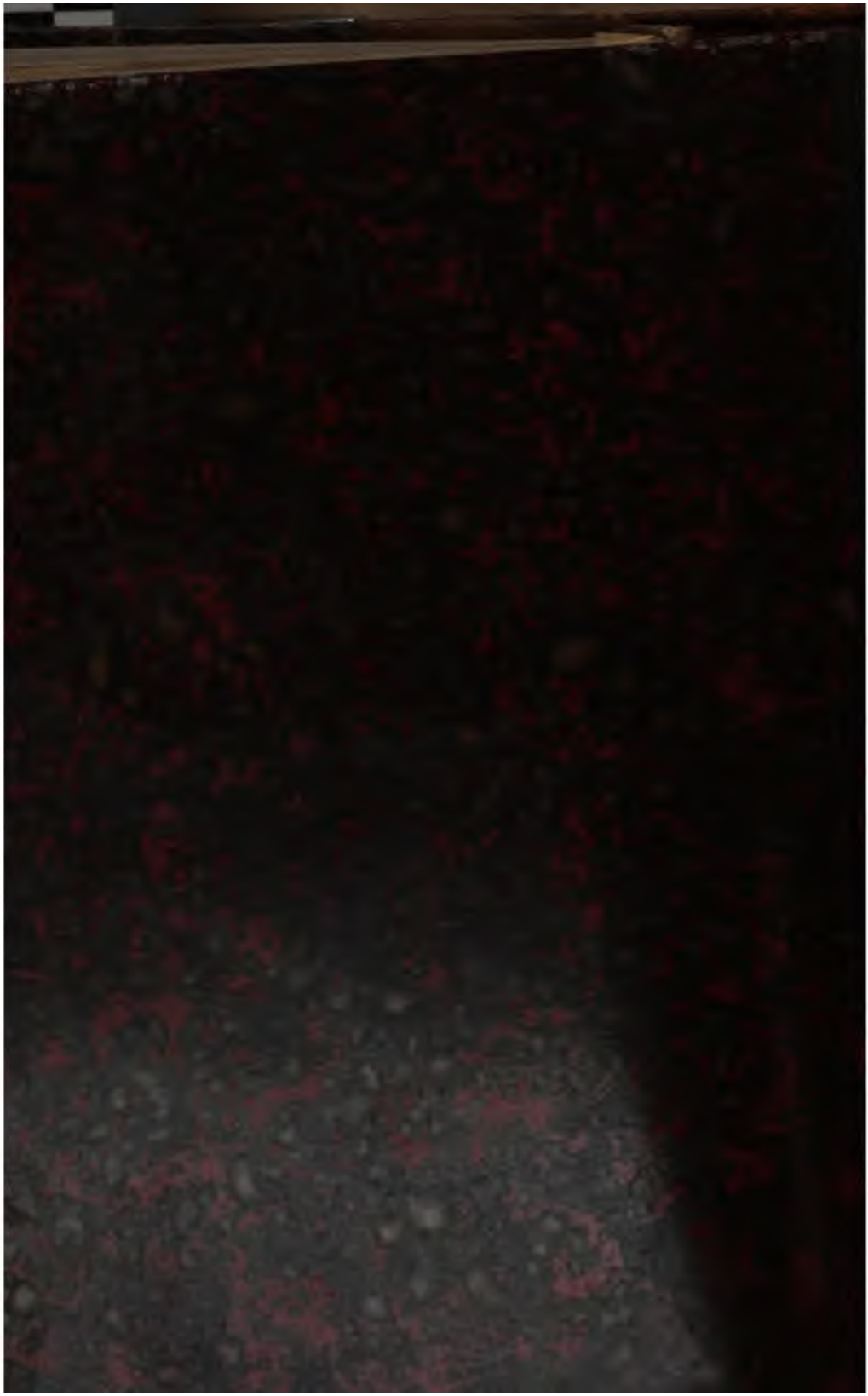

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